Howell Instruments, Inc.

Contract Number M67854-97-C-2117

Commercial Operations and Support Savings Initiative

(COSSI)

FINAL REPORT

JETCAL2000® Analyzer H337PA-603

OPERATIONAL TEST AND EVALUATION (OT&E)

ON

H-53E/J AIRCRAFT

AND

H-46D/E AIRCRAFT

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1-0 EXECUTIVE SUMMARY

Howell Instruments Inc. is pleased to provide the JETCAL2000® Analyzer that implements a turn-key portable test set solution for testing installed turbine engines in H-46D/E and H-53E/J aircraft. This portable test set proposal takes an innovative approach to providing a cost-effective solution for lowering Operations and Support (O&S) costs.

Howell Instruments, Inc. is a well-respected engine instrumentation company with over 52 years experience of design and manufacture of commercial and military systems. Howell developed the JETCAL2000® Analyzer prototype in 1991 for Gulfstream aircraft. Other versions of the JETCAL2000® Analyzer demonstrated their value when used by numerous airlines on their SAAB 340 and CN 235 fleets to determine pre- and post-maintenance status and temperature margin on CT7 series engines. The JETCAL2000® Analyzer continues to prove its benefits in various military and commercial applications while undergoing timely upgrades to maintain its state-of-the-art technology. The leverage of adapting this developed, commercial technology to Army helicopters will prove beneficial to the government.

NAVAIR PMA261 (H-53 PMO) and PMA299 (H-60 PMO) identified to industry in February 1997 that the O&S costs for each of these specific Navy aircraft were too high and solicited information from industry in recommending new and innovative methods to address lowering O&S costs for these aircraft through the Commercial O&S Savings Initiative (COSSI) program. Additionally, Cherry Point NADEP identified in 1995 a need to check the accuracy of H-46 and H-53 torque indicating systems.

Howell Instruments, with sponsorship of NADEP Cherry Point, submitted a proposal to the COSSI Program Office in the spring of 1997 for a single engine portable test cell for the CH-46D/E and CH/MH-53E aircraft. This proposal was selected for award in June of 1997 based on its 16 to 1 cost savings potential. This COSSI proposal ranked third out of 14 proposals approved for US Navy cost savings initiatives.

1-1 COSSI REQUIREMENTS AND SCHEDULE

COSSI requirements for Stage I completion were defined to be within two years of contract award date. An 845 Agreement was negotiated and signed on September 18, 1997 with agreed upon completion of the Operational Test and Evaluation (OT&E) by November 1, 1998. Modification to this contract for extension was granted in March 1998, April 1999, July 2000, April 2001, and December 2001 for completion of OT&E on June 30, 2002. These extensions were a result of test schedule slippage due to lack of funds for union mechanics at Cherry Point NADEP and various other reasons which created delays in completing Stage I testing. Final testing was completed on June 5, 2002.

1-2 MULTIPLE ENGINE CAPABILITY REQUIRED

At the initial program review, US Navy personnel attending stated that testing all installed engines on a single flight was required due the high operating cost of the helicopter. They stated the operating cost per flight hour as $6,100 for the CH-46D/E aircraft and $11,700 for the CH/MH-53E. Howell accepted the requirement, which added significant engineering and hardware costs (H-46 – one engine additional installation kit, H-53 – two additional engine installation kits). The initial agreement between NADEP and Howell

Instruments was a total program cost of $403,000 with a 10.9% cost share contribution from Howell. After the project was changed to include multiple engine testing, the total program costs increased to $787,592 as of December 31, 2000. This was composed of the original $403,000 cost, plus $384,592 additional accrued cost, less Howell's agreed upon cost share of $44,000. Howell Instruments' total contribution is $428,592**.** This represents a 54.4% Howell cost share.

1-3 NEED FOR TEST CAPABILITY

Stage I of this COSSI was designed, in cooperation with NADEP Engineering, to demonstrate a new and innovative method of addressing turbine engine maintenance costs at the operational level. Howell Instruments' JETCAL2000® Analyzer was used to perform test cell equivalent evaluations of installed engines, verify their health, and show abnormal module operation. The primary driver for implementing the new technology was the high cost associated with removing large numbers of engines from aircraft for low power that operated satisfactorily on the test cell with no fault found.

The JETCAL2000® Analyzer provides an improved method for testing installed turboshaft engines. It checks cockpit instruments, records data and analyzes performance with a diagnostic output. Howell's patented Referred Engine Diagnostic Data (REDD) Data Reduction Program (DRP) enables even the novice user to determine an engine's performance potential with extreme accuracy. REDD also provides detailed information necessary for troubleshooting, determining the actual fault, then performing the proper repair–the first time. The diagnostic feature reduces the number of flights needed to verify engine performance and verifies airworthiness for fleet operations. Also, when used prior to an engine removal, the diagnostic data will assist the engine shop in determining the true malfunction and correct repair action, therefore lowering the number of test cell-engine shop-test cell returns.

Portable test cell equivalent instrumentation for testing an installed engine provides the fleet operational level maintenance a portable tool. It can be used to test and troubleshoot impending faults and adjust and verify repairs within a gas turbine engine without removing the engine from the airframe. The digitally recorded engine operating data with its ease of electronic transmission provides the potential for a powerful central database capability. The condition of each engine in the fleet can be determined, stored, and made available on request to management. Additional benefits are discussed later.

1-4 TESTING PROCESS

The purpose of Stage I OT&E testing was to verify that the JETCAL2000® Analyzer:

1. Accurately measured and recorded required engine data,
2. Analyzed the data and presented faults in a manner that significantly enhanced maintenance personnel's ability to identify engine problems,
3. Produced information that demonstrated a significant return on investment (ROI),
4. Can be fielded in the current Navy maintenance environment.

During the OT&E, engines tested were either fleet maintained (scheduled and unscheduled) or newly repaired and released by intermediate or depot test cells. All maintenance was performed in accordance with existing procedures and test equipment. All savings are based on preventing false removals due to faulty instrumentation and/or

detection and correction of incorrect maintenance actions performed during engine adjustments (such as guide vane adjustments).

1-4.1 Operational Benefits When Using JETCAL2000® Analyzer with REDD

- Eliminate falsely rejected engines due to cockpit instrument errors.
- Validate aircrew test procedures for stable operation and appropriate thermal equilibrium for data acquisition. (Unstable operation during data acquisition can fail good engines. Lack of thermal equilibrium during data acquisition can pass unacceptable engines).
- Confirm acceptable engine condition using multiple factors. Display accurately the effects of adjustments on engine performance.
- Detect insidious faults that would otherwise go undetected using existing procedures and equipment. These faults will shorten engine life if not corrected.
- Show need for compressor wash by identifying low compressor pressure ratio before an engine is rejected for low power. Wash lowers gas temperature, slows deterioration and delays onset of low power.
- Confirm accuracy of indicated data by comparison to thermodynamic model values. Parameters that indicate out of limits are identified for confirmation.
- Identify fuel manifold leaks or flow path obstructions by constantly measuring fuel pressure at fuel flow conditions.
- Identify turbine failure mode not covered in troubleshooting trees.
- Identify abnormal operation of compressor, overall (burner section) and/or turbine sections of the engine.
- Eliminate requirement for pre-induction test cell operation for JETCAL2000® Analyzer tested engines. REDD diagnostics show the abnormal section of the engine needing attention.
- Reduce test cell rejects after engine shop repair by prompting attention to components identified by REDD as needing repairs.
- Confirm the efficacy of repair work performed using REDD data. In particular, REDD can verify the effect of mechanical adjustments for engine performance.
- Validate engine performance and airworthiness after engine installation with an electronic record that shows how the engine performed and how it was tested.
- Reduce logistic footprint and lowers overall system cost by use of standardized portable test equipment for multiple aircraft.
- Does not degrade mission capability – no weight is added to mission aircraft. After engine test, aircraft is returned to its original mission configuration.

1-5 TEST RESULTS

The potential savings demonstrated in the Stage I OT&E from reducing the removal of good engines, finding hidden faults, making correct adjustments to engines, and reducing the window of uncertainty in interpreting test data has a compelling 30+ to 1 ROI for each type aircraft. Savings from improved flight safety by early detection, repair of potentially

hazardous low power engines, and elimination of unnecessary repairs prior to test cell runs are significant but not claimed. Implementing Stage II of this COSSI program offers Navy and Marine users a potential reduction in combined H-46 and H-53 propulsion O&S costs of more than $67 million and payback in less than two years.

1-6 RECOMMENDATIONS

COSSI program Stage II should commence immediately based on Stage I OT&E results. Stage II as defined under the COSSI 845 Agreement consists of ten units for CH/MH-53E aircraft at $224,200 each, and nine units for H-46D/E at $201,000 each.

The H337PA-603 test set should be fielded immediately. REDD and the JETCAL2000® Analyzer work. The concept has been proven to significantly improve knowledge of an engine's performance potential and to identify abnormalities in engine modules through the use of diagnostics. The output of the data analysis program gives the user the ability to accurately verify engine status. The system will demonstrate immediate value when used following initial engine installation, on a regular interval, during pre-phase induction engine runs, when a power check is failed, and for installed evaluation prior to engine removal.

1-7 CONCLUSION

The expected savings from fielding this system provide a compelling rationale in terms of operational readiness, ROI, and flight safety. In particular, the current impact of flying de-rated engines requiring (for instance) five and a half turns of fuel control trim adjustment to reach rated power proves the need for this maintenance analysis capability to address on-wing marginal engine problems and short on-wing times. The Navy and Marines should begin Stage II of this COSSI program as soon as possible.

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2-0 BACKGROUND

This COSSI project outlined the proposed cost of modification from an existing commercial design Non-Recurring Engineering (NRE) costs, to meet US Navy requirements for fielding Ground Support Equipment. In 1997, COSSI required a minimum of 10% cost sharing by the Contractor. Howell Instruments planned to share the costs of this COSSI Project with the government. Of the $403,000 total Stage I costs, Howell proposed to fund the NRE costs at $44,000 for 10.9% of $403,000 total cost. This proposal was for a single engine set of test cell equivalent instrumentation for installed turboshaft engine testing. The H-53E would need three test flights to check all three engines.

The 1997 Net Present Value calculations used in the proposal for the single engine JETCAL2000® Analyzer project showed the value to be $42.7 million. The benefit-to-cost ratio is 16 to 1. The break-even point is 2.2 years. More importantly, with a $2.9 million discounted-value investment, a Return on Investment (ROI) of 10 to 1 occurs during the seventh year, resulting in a $30 million savings in Operations and Support (O&S) costs. The test results supported this “win-win” situation for the both the government and Howell Instruments. The cost benefit analyses using OT&E test results and the cost of multi-engine installation kits for each type aircraft are included in APPENDIX B and APPENDIX C of this report.

2-1 MULTIPLE ENGINE CAPABILITY REQUIRED

US Navy personnel attending the initial program review stated that testing all installed engines on a single flight was required due the flight hour cost of operating the helicopter. NADEP gave the operating cost per flight hour as $6,100 for the CH-46D/E aircraft and $11,700 for the CH/MH-53E. Howell accepted the multi-engine requirement that added significant engineering and hardware costs (H-46 – one engine additional engine installation kit, H-53 – two additional engine installation kits). Total program costs increased to $787,592 as of December 31, 2000. This was composed of the original $403,000 cost, plus $384,592 additional accrued cost. Howell Instruments' total contribution is $428,592**.** This represents a 54.4% Howell cost share as a result of the expanded multiple engine test capability provided and the delays in completing Stage I testing.

COSSI requirements for Stage I completion were defined to be within two years of Contract Award date. An 845 Agreement was negotiated and signed on September 18, 1997 with an agreed upon completion of the Operational Test and Evaluation (OT&E) by November 1, 1998. Modification to this contract for extension was granted in March 1998, April 1999, July 2000, April 2001, and December 2001 for completion of OT&E on June 30, 2002. Due to program changes and testing delays, the final cost sharing between the Government and Contractor is now 54.4% for the Contractor and 45.6% for the Government. This COSSI far exceeded the government requirement for cost sharing.

2-2 STAGE I OT&E TESTING

Thirty aircraft of each type coming to NADEP Cherry Point during a 6-month test period were to be tested with the H337PA-603 Analyzer as an OT&E of the test sets’ capabilities.

The inbounds represent aircraft arriving for depot work with used field condition engines and some of the outbound aircraft with newly refurbished engines from the test cell. NADEP Cherry Point cancelled the six-month H337PA-603 OT&E test after one month flight testing of only three H-46 and two H-53E aircraft. The reason was that funds to support union mechanics installing and removing the test sets had not been provided in the test planning. Union rules preventing crew chiefs from installing the test set at depot were not known during planning. However, significant unexpected test results on engine condition were obvious even from the abbreviated NADEP test data.

H337PA-603 Test Set accuracy was verified by operating the test set connected in parallel to the same engine being run on the MCAS New River T58 test cell. This provided certified instrumentation readings against which to verify the accuracy of the test set readings. Test set readings compared with the test cell instruments were well within the specified accuracy.

NAVAIR 4.4.1**,** Propulsion**,** reviewed the available data and decided that three additional aircraft of each type would provide adequate testing to validate the test objectives. NAVAIR 4.4.1 coordinated an effort to move the Stage I OT&E test to HMX-1 prior to 9-11-2001. The subsequent tempo of operations at HMX-1 and the need to complete EMI testing on the JETCAL2000® Analyzer forced a delay until March 26, 2002. EMI testing was satisfactorily completed at the NAS Patuxent River test facility January 31, 2002.

Three H-46E aircraft were tested by HMX-1 at Quantico, VA the last week of March 2002. Five of the six engines would not produce rated power and three of the six were operating below the 95% power reject level. Two HMX-1 maintenance technicians demonstrated installation of the H337PA-603 test equipment in 45 minutes and removal in 20 minutes.

One of the first two JETCAL2000® Analyzer prototypes is being used as a full time engine monitoring system on a CH-46E at HMX-1, MCAS Quantico. The aircraft is the test bed aircraft for the initial delivery T58-GE-16A engines under the Engine Reliability Improvement Program (ERIP). The recorded data from the JETCAL has established performance base lines and tracked performance during the testing program. The REDD information from the first engine tested shows rated torque with 16 °C Gas Temperature (GT) margin and 0.2% gas generator speed (Ng) margin. The engine capability at the limits is 105.0 % rated torque at GT limit and 0.2% at the Ng limit.

The data was very valuable in understanding the severity of a torque split problem encountered in initial testing and in validating its correction. To help with understanding the torque split problem, an additional cable was made to connect the collective and actuator position voltages from the Engine Condition Control System (ECCS) to the JETCAL2000® Analyzer. The voltages were measured and recorded for determination of their value EACH QUARTER OF A SECOND during operation. The accurate data was very helpful in understanding the situation.

The 4th MAW, Edwards AFB, CA, tested three additional H-53E aircraft in May of 2002. Seven of the ten engines tested had Variable Guide Vanes (VGVs) operating outside the acceptable bands. Four of the engines had no temperature margin at rated power but they all had acceptable temperature margin at 10% de-rate (380 SHP less per engine). Two out of three engines were not topped correctly, preventing the engines from reaching the high point on four-point check. One engine (s/n 01816129) required 5½ turns in on the fuel control trim screw before it would reach the 4th point on the nomograph check. Engine

washes can bring high-risk low Compressor Discharge Pressure (CDP) vs. Ng readings back into acceptable operation. Rigging VGVs back to basic returned engine s/n 0816132 to *deteriorated* from *high risk* status. The users of the system stated that the test set provides data faster, monitors all three engines at the same time, and presents data that is easy to interpret and so understand aberrations in engine operation.

2-3 RESULTS FROM STAGE I OT&E

Stage I OT&E was completed in July 2002 with positive results. The Net Present Value (NPV) calculation with the cost of the multi-engine test capability confirmed a cost savings of $67+ million (H-53 = $36.676 million, H-46 = $30.397 million). Sections 2 and 3of this report provide the H-53 and the H-46 aircraft O&S Spreadsheet Analyses results along with OT&E Facts and Assumptions used in the analysis. APPENDIX A of this report provides details on the data used to establish success for Stage I completion.

2-4 H-53 JETCAL2000® ANALYZER O&S Saving Analysis

The following H-53/T64 cost data was derived from the Navy VAMOSC DATA BASE, Integrated Logistics Management Support Team (ILMST) notes, and discussion with various levels of T64 management.

2-4.1 T64 Statistics

- Total T64 Engine Removals Per Year = 180.
- T64 depot rework = $10,466,000 annually
- Repair at "I" level = 120 engines (2/3), at depot = 60 engines (1/3).
- H-53 type distribution 42 H-53D's, 160 CH-53E's and 40 MH-53E's.
- All engine types average MTBR = 431, MTBF = 938:
  - -413 (MTBR = 525, MTBF = 1100),
  - -416 (MTBR = 350, MTBF = 620),
  - -416A (MTBR = 300, MTBF = 750),
  - -419 (MTBR = 550, MTBF = 1280).
- Average fuel cost per flight test hour $962 – 5000 PPH AT $1.25/GAL.
- MH-53E costs $12,500/ flight hour, CH-53E costs $11,500/flight hour.
- MMH/fl hr – CH-53E = 44.9 Hours/Flt. Hour and MH-53E = 57.1 Hours/Flt. Hour.

2-4.2 Values Used In Analysis

- Cost per Engine for test cell run prior to repair = $6,000.
- Cost per Engine removal and replacement = $5,000.
- Cost for transportation to and from depot = $8,000 – Average $4,000 each way.
- US Navy Safety Center gives engine replacement cost at $88,400 to the end user.
- Removal of an engine from an aircraft for return to a depot test cell for repair/investigation costs $150,000. Data source was AIRLANT propulsion.

- The portable engine test set equipment transfers a NIST calibrated reference indication to the aircraft. Identifying and correcting cockpit instrumentation calibration will minimize false-removal of engines. It is anticipated that use of the JETCAL2000® Analyzer test set's calibrated reference readings before engine removal will eliminate any false removals due to cockpit instrument errors.
- T64 ILMST data gives that test cell runs found no defect on five engines in 2001. Each false removal of an engine falsely lowers T64 fleet MTBR.

2-4.3 Cost Saving Rational

Each subsequent year's savings are based on the number of test sets deployed: 1 set, 6 sets, and 10 sets. Savings are $4,590,000 for the second year with 6 fielded test sets, and savings are $8,415,000 for the third and subsequent years with 10 fielded test sets.

Work sheets in APPENDIX B show allocation of the savings into cost elements. During allocation to specific cost elements, the input value was reduced an additional 60%. Even with the conservatism in input numbers, the net present value is $36,676,000 with a ranking index of 37.15. The total investment would be recovered in less than two years.

2-4.4 Translating Test Data Into Savings

Tables in APPENDIX A give the condition indicated by the JETCAL2000® Analyzer for each engine tested. For the T64, see Table 7-1-1 and Table 7-2-1.

Engines tested are either fleet maintained using currently directed procedures and test equipment or newly repaired as released by intermediate or depot test cells. All savings are based on the value of improving the MTBR by lowering the engine operating temperature and avoiding cost of wrong removal decisions due to faulty instrumentation.

1. Sixteen T64 engines were tested during the OT&E period. Seven engines (or 44% of tested engines) were operating at less than rated power but above the low power reject level at 90% rated power. Current troubleshooting trees lead to an engine wash only after rejection for low power. Engines operating more than 1 CPR (pressure ratio) low were considered to have a dirty compressor. Washing the engines improved the temperature margin and corrected the low power in four of the seven cases. Removal of these four engines was delayed producing an extended period of operation due to lowered operating temperatures. T64 average MTBR is 450 hours. Delaying removal by 45 hours because of lower operating temperatures will produce a savings of 10% of the cost of sending an engine to depot, or $15,000. Four engines during the 2-month period of active testing gives 24 engines per year per JETCAL2000® Analyzer for a compelling cost savings of $360,000 (24 engines/year X ($15,000/engine/test set)). Engine washes are already being done periodically and when an engine fails a 4-point test. These JETCAL2000® Analyzer tests were done on fleet engines being managed by current wash procedures. Due to the small sample size, only a $150,000 savings from removals delayed by water wash was used in the benefit study.
2. Seven of nine T64 engines tested in the two-month period had VGVs operating outside the recommended operating band. Two of the T64 engines were newly overhauled and accepted by the depot test cell, yet were operating with unacceptable VGV settings. Correction of VGVs to mid-band on these two engines will certainly delay rejection for low power. Four hundred fifty hours of extended life (the current average T64 MTBR)

is worth $150,000, the cost of a shop visit. Seven engines X 6 test periods per year X $150,000 = $6,300,000. Assume VGV tuning is only 10 percent effective at returning gas temperature margin to expected values for used engines. The $6,300,000 savings is reduced to $630,000 per test set per year. Only $525,000 was used for the cost study. JETCAL2000® Analyzer/REDD performance information shows how a change in VGV impacts engine margin. Therefore, adjustments that degrade engine performance are immediately obvious. This is not the case with other test sets that do not provide a full record of engine performance. Current test of VGV operation only checks for in band operation at three specified gas generator speeds.

3. The test set brings National Institute of Standards and Testing (NIST) accuracy to the cockpit for checking the readings on cockpit instruments. Experience has been that 70% of aircraft tested have one or more cockpit instruments providing out-of-tolerance indications. Correction allows pilots to regain ability to correctly observe limits and assess engine condition. One T64 engine was rejected with a 15% low torque instrument reading. Correction of the torque system error showed satisfactory engine performance. A good engine indicated to be bad by an invalid instrument was shown to be good by the JETCAL2000® Analyzer. Remaining in service would produce a $150,000 saving. One case found in the two-month test period times 6 would produce a savings of $900,000 per unit per year. Because of the small sample size in the test, only 10% or $90,000 per year savings was used per unit for extending the MTBR of engines failed by an invalid cockpit instrument.

   Elimination of the pre-teardown test cell run when a JETCAL2000® Analyzer test is completed before removal offers a significant cost saving.. The REDD data will show the section of the engine that is operating abnormally. Experience has shown that REDD data from a test cell run will cut repeat teardowns from an average of more than three to, conservatively, only one. (Data from T53 engines using a PEATS test set running in parallel with Army Mobile Engine Test Set (METS) facility.) With the necessary test sets to check all 180 removals in a year, the JETCAL2000® Analyzer could save test cell runs at $6,000 each or $1,080,000 per year. Correct identification of faults could eliminate second shop visits and remove and replace trouble-shooting with another million dollar saving.

   NOTE: No credit was taken for these potential savings in this cost study.

2-4.5 Total Savings One Unit - One Year

Savings from Items 1 thru 3 above, ($150,000, $525,000, and $90,000) add up to an annual savings of $765,000 from one JETCAL2000® Analyzer unit used for one year. See APPENDIX B for cost allocation in the COSSI supplied worksheet.

2-4.6 Stage II Implementation Costs – H-53 Aircraft

- Stage II implementation is the purchase of 10 test sets, each containing one H337PA-603 control unit and one installation kit with three-engine capability. Fielding of kits: 5 delivered in fourth quarter 2003 followed by 5 in first quarter 2004.
- Budgetary price for each H337PA-603, JETCAL2000® Analyzer portable engine test set is $77,000, and each H338P-53 - Installation Kit costs $158,000. Total cost for three engine portable T64 test capability per H-53 aircraft = $235,000.

2-4.7 H-53/T64 O&S Savings Spreadsheet

Proposal Title PORTABLE TEST CELL - JETCAL 2000(R)
Lead Proposer HOWELL INSTRUMENTS
Military Customer NAVY/MARINE H53 AIRCRAFT

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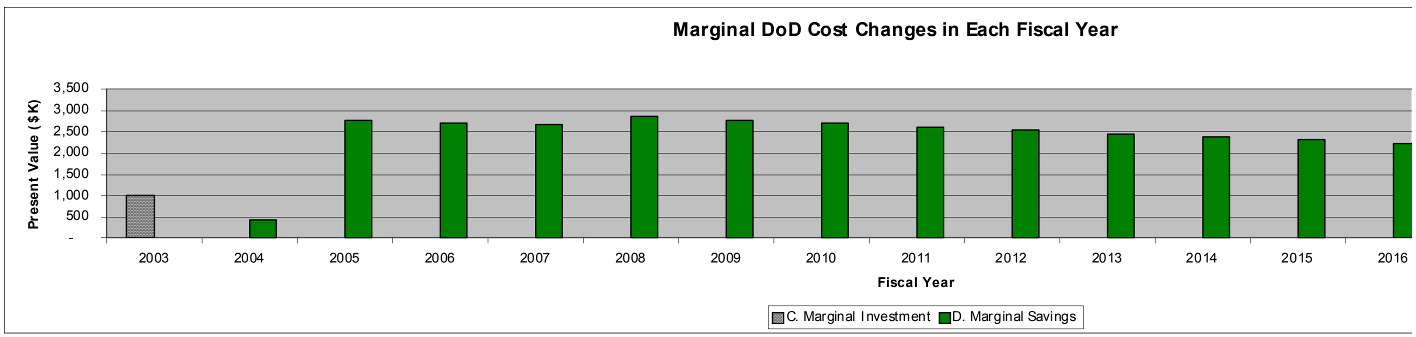
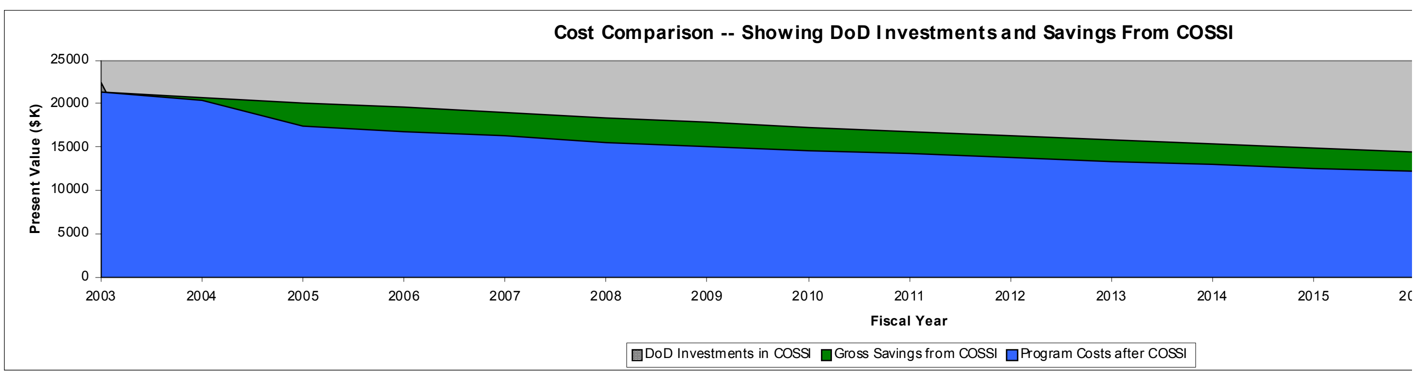
Calculation of NPV and Ranking Index

Government Fiscal Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
A. Present Value of Costs When COSSI is Implemented	22,416	20,333	17,380	16,841	16,270	15,514	15,048	14,595	14,156	13,731	13,318	12,918	12,529
B. Present Value of Baseline Costs – No COSSI	21,402	20,758	20,134	19,529	18,941	18,372	17,819	17,284	16,764	16,260	15,771	15,297	14,837
Net Impact on DOD Funding (B minus A)	(1,015)	425	2,754	2,688	2,671	2,858	2,772	2,688	2,607	2,529	2,453	2,379	2,308
C. Marginal Investment	1,015	-	-	-	-	-	-	-	-	-	-	-	-
D. Marginal Savings	-	425	2,754	2,688	2,671	2,858	2,772	2,688	2,607	2,529	2,453	2,379	2,308

NPV (D minus C)	**36,676**
Ranking Index (D divided by C)	**37.15**





2-5 H-46 JETCAL2000® ANALYZER O&S Saving Analysis

The following cost data was derived from the Navy VAMOSC DATA BASE, and PMA 226 Integrated Logistics Management Support Team (ILMST) notes, and discussion with various levels of T58 management.

2-5.1 T58 Statistics

- FY01 Hours Flown –H-46E = 40,038, -H-64D = 19,520.
- Total T58 Engine Removals Per Year = 132.
- Repair at "I" level = 88 engines (2/3), at depot = 44 engines (1/3).
- H-46 type distribution 79 H-46D's, and 229 H-46E's.
- Both engine types average MTBR = 438, MTBF = 860:
- -16 (MTBR = 525, MTBF = 1100),
- -420 (MTBR = 350, MTBF = 620).
- Average fuel cost per flight test hour $327 – 1700 PPH AT $1.25/GAL.
- H-46D costs $6,100/ flight hour, H-46E costs $6,100/flight hour.
- MMH/fl hr – H-46D = 35.53 Hours/Flt Hour and H-46E = 23.05 Hours/Flt Hour.

2-5.2 Values Used In Analysis

- Cost per Engine for test cell run prior to repair = $5,000.
- Cost per Engine removal and replacement = $5,000.
- Cost for transportation to and from depot = $8,000 – Average $4,000 each way.
- US Navy Safety Center gives engine replacement cost at $69,000 TO USER.
- User gets additional use of engine equal to 30% of the MTBR for a $20,700 savings.
- Of the 76 low power engines removed in 2001 – Test cell found 25 engines were Ready For Issue (RFI).
- Each "I" level removal of a RFI engine prevented saves $79,000. Depot cost less transportation.

2-5.3 Cost Saving Rational

- The annualized value of the savings is 6 times the value found for the 2-month test period.
- Total annual savings is the annualized one unit savings times the number of units fielded in that year. Six units are in use during the second year and 10 units in the third year.
- Removal of an engine from an aircraft for return to a depot test cell for repair/investigation costs $87,000 ($5,000 + $5,000 + $8,000+ $69,000). AIRLANT data was not available.
- The portable engine test set equipment transfers a NIST calibrated reference value for each cockpit instrument. Correcting cockpit instrument errors will minimize false-

removals of engines. It is anticipated that use of the JETCAL2000® Analyzer® test set's calibrated reference readings before engine removal will eliminate any RFI engine removals due to cockpit instrument errors.

- T58 ILMST data gives that approximately one third of the engines–25–removed for performance in 2001 operated satisfactorily on pre-repair test cell runs and were tagged RFI. Correcting a false removal keeps an engine in service longer with a positive impact on MTBR. The cost savings possible based on stopping the FY01 false removals is conservatively $517,500 per year. (25 X $20,700 (30% MTBR extension)).

2-5.4 Translating Test Data Into Savings

1. Table 8-2-1 and Table 8-6-1 give the condition indicated by the JETCAL2000® Analyzer for each T58 engine tested.
   Engines tested during the Stage I OT&E evaluation were either fleet maintained using currently directed procedures and test equipment or newly repaired as released by intermediate or depot test cells. Savings are based on the value of improving the MTBR by lowering the operating temperatures (increasing gas temperature margin) and avoiding wrong decisions to remove an engine due to faulty instrumentation.
   Experience has shown that 70% of aircraft with round dial instruments have one or more cockpit instruments providing out-of-tolerance indications. Torque accuracy critical to engine reject criteria is checked by the JETCAL2000® Analyzer. It calculates a model based <u>expected</u> torque that can be checked with the <u>indicated</u> torque. The expected torque is derived from the engine performance model using the operating values of Ng, Turbine Gas Temperature (TGT), fuel flow, and Compressor Discharge Pressure (CDP). Differences greater than 2% between the expected and indicated torques should be checked prior to rejecting an engine. Faulty torque readings can thus be identified by a torque accuracy check that is not currently available. Correction of an instrument error restores pilot's ability to correctly observe engine performance and aircraft limits.
2. Four of the fourteen engines had torque instrument errors greater than 5% or 70shp. Correctly adjusting the torque system readings will produce $26,100 ($87,000 X 30% repair cost) savings in each case by a 30 per cent increase in engine usage before removal from the indicated 70 SHP margin increase in power margin. Two months of testing produced a savings of $104,400 (4 engines by $26,100 each) from MTBR increases. Total savings are $626,400 per year per unit ($104,400 per 2 months X 12/2 months per year).
3. The JETCAL2000® Analyzer test set provides detailed engine performance information that supports finding the optimum setting of the VGVs with the engine installed. Current maintenance directives prohibit "O" level adjustment of the VGV. Finding the optimum setting of vanes is possible based on the gas temperature and Ng speed margins provided by the REDD data analysis program. Optimum VGV tuning has produced an increase in gas temperature margins by as much as 30 °C that equates to a power margin increase of 140 SHP.
   A potential savings is available from of the optimum VGV adjustments to lower an engine's operating temperature and increase its power margin, which will extend engine on wing time. T58 Maintenance Directives must be modified to allow "O" level

maintenance using the JETCAL2000® Analyzer test set to take advantage of the potential life extension from optimum VGV tuning. Assuming a linear relationship between power margin and time on wing will allow use of 60% of engine current MTBR cost for a savings value of $52,200 ($87.000 X 315/525). Nine of fourteen engines tested had less than rated power and had VGV operation that could have improved performance. A savings of $2,818,000 for one JETCAL2000® Analyzer for one year. For a conservative approach, consider that only five of the nine engines with VGV optimization will recover performance margin of at least 15 degrees gas temperature margin (70 shp) at $130,500 for the two-month test period or (130,500 X 6) $783,000 per unit per year.

4. Fourteen T58 engines were tested during the six-month OT&E period. Four (4) engines passed by the nomograph were found to have power below the 95% minimum. The REDD DRP found the cause of low power to be other than engine related in the four cases. Identification and correction of these cases prior to engine removal will result in 10% MTBR life cost ($87,000) for a savings of $34,800 ($8,700 X 4) each during the two-month period, or $208,800 per year per unit.
5. The test data from a ground test reported that an engine was performing below minimum levels. Five test flights later, the aircrew reached the same decision. If the information from the test set had been used, only one test flight would have been required with COSSI test set. Test flights take one hour each at $6,100/flt hour. Four flights would have saved $24,400 in the two-month period, or $146,400 (6 test periods per year X $24,400) per unit per year.
   Elimination of the pre-teardown test cell run when a JETCAL2000® Analyzer test is completed before engine removal offers a significant cost savings. The REDD data from the JETCAL2000® Analyzer test will show the section of the engine that is operating abnormally. Experience has shown that REDD data from a test cell will cut repeat teardowns from an average of more than three to, conservatively, only one. (Data from T53 engines using a Portable Engine Analyzer Test Set (PEATS) running in parallel with Army METS test facility). With test sets available to check all removals in a year, the JETCAL2000® Analyzer could save 133 test cell runs at $5,000 each or $666,000 per year. Correct identification of faults could eliminate a second shop visit, and eliminate remove and replace trouble-shooting worth an additional million dollars. NOTE: No credit was taken for these potential savings in this cost study.

2-5.5 Total Savings One Unit – One Year

- Adding the savings from paragraphs 2 thru 5 above ($626,000, $783,000, $209,000 and $146,000), savings total $1,764,000 per unit per year. Due to the short test period and the need to change the no Field VGV adjustment policy, the annual calculated savings of $1,764,000 is reduced to approximately 44% for a conservative value of $765,000 per unit per year.
- Each subsequent year's savings are based on the number of test sets deployed, 1 set,6 sets, then 11 sets.
- Worksheets included as APPENDIX B show the allocation of cost savings to the applicable propulsion cost elements in the life savings study.

2-5.6 Stage II Implementation Costs H-46 Aircraft

- Stage II is an additional purchase of nine units, one test unit and one two-engine run kit for use at H-46 operating locations.
- Stage II fielding of kits, 3rd quarter - FY03 - 5 delivered, and 1st quarter FY 04 - 4 delivered.
- Budgetary price each for engine tester $77,000, Two Engine Run kits $124,000. Total cost for H-46 aircraft with two-engine capability equals $201,000.

2-5.7 H-46/T58 O and S Savings Spreadsheet

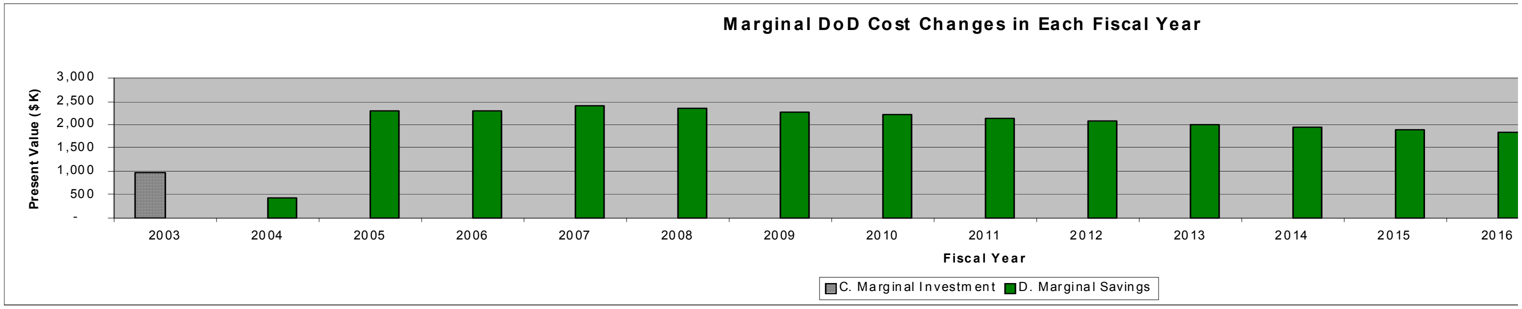
Proposal Title PORTABLE ENGINE TEST CELL
Lead Proposer HOWELL INSTRUMENTS
Military Customer NAVY/MARINE H46 AIRCRAFT

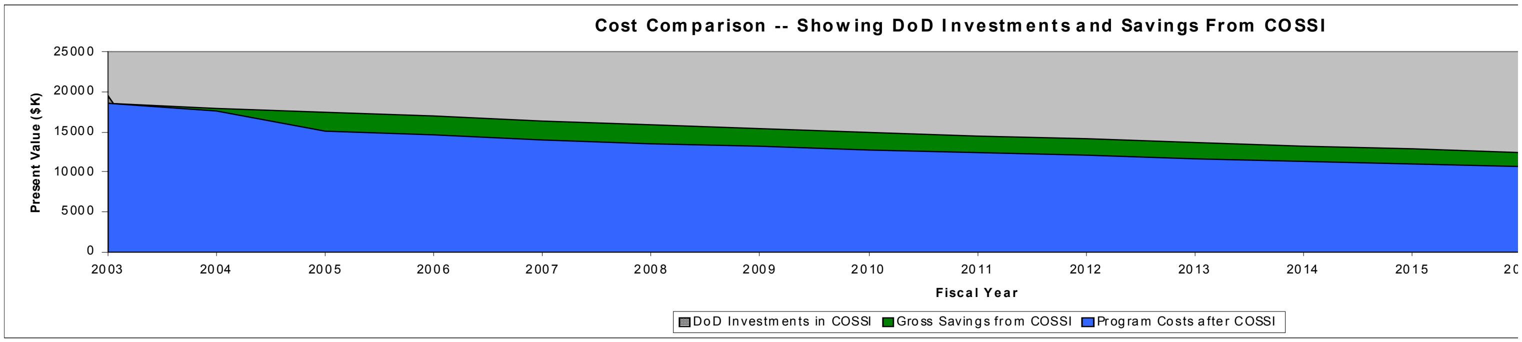
-

Calculation of NPV and Ranking Index

Government Fiscal Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
A. Present Value of Costs When COSSI is Implemented	19,517	17,580	15,161	14,639	14,018	13,597	13,188	12,791	12,407	12,034	11,672	11,321	10,981
B. Present Value of Baseline Costs -- No COSSI	18,559	18,005	17,469	16,943	16,434	15,940	15,460	14,996	14,545	14,107	13,683	13,272	12,873
Net Impact on DOD Funding (B minus A)	(958)	425	2,308	2,305	2,416	2,343	2,273	2,204	2,138	2,074	2,011	1,951	1,892
C. Marginal Investment	958	-	-	-	-	-	-	-	-	-	-	-	-
D. Marginal Savings	-	425	2,308	2,305	2,416	2,343	2,273	2,204	2,138	2,074	2,011	1,951	1,892

NPV (D minus C)	**30,397**
Ranking Index (D divided by C)	**32.73**





3-0 TEST REPORT

The commercially used JETCAL2000® Analyzer manufactured by Howell Instruments, Inc., Fort Worth, Texas, was modified into Part Number H337PA-603 for use on Navy helicopters. The test set is a turbine engine monitor with test cell accuracy, data recorder, and data analysis system. The data analysis uses artificial intelligence methods to determine installed-engine condition and performance. The graphic outputs enable inexperienced mechanics to isolate engine problems with the expertise of the most seasoned mechanics and engineers.

The JETCAL2000® Analyzer test set designed for this COSSI tests both T58 and T64 engines installed in H-46 and H-53 airframes. Two mechanics installed the test set on an H-46E in 0.8 hours and removed it in 0.3 hours. Aircraft configuration was returned to normal after test set removal. Each aircraft maintained its pre-existing mission capability. Added weight from the test set and installation kit was carried only on the test flight.

Two JETCAL2000® Analyzer test sets, with one multi-engine installation kit for the H-46 and one multi-engine installation kit for the H-53 aircraft, were delivered to MCAS Cherry Point in July 1998. Howell trained MCAS Cherry Point personnel to operate the equipment. These trained personnel used the test sets for one month out of a planned six months on aircraft coming to and leaving the depot.

3-1 TEST SYNOPSIS

1. Two H-53 and two H-46 flights were successfully completed at NADEP Cherry Point, NC during August and September 2000. Three H-46E flights were completed at HMX-1, Quantico MCAS during late March 2002. Details from these flights follow in APPENDIX A of this report. The H337PA-603 test equipment and the diagnostic analysis disclosed abnormalities and hidden faults in five out of eight NADEP T58 engines that had been signed off as flight worthy using nomograph procedures.
2. The JETCAL2000® Analyzer was used in parallel with the MCAS New River T58 test cell where its accuracy was verified against Test Cell instrumentation.
3. NAVAIR 4.4.1, Propulsion, reviewed the available data and decided that three additional aircraft of each type would provide adequate testing to validate the test objectives. NAVAIR 4.4.1 coordinated an effort to move the Stage I OT&E test to HMX-1 prior to 9-11-2001. The subsequent tempo of operations at HMX-1 and the need to complete EMI testing on the JETCAL2000® Analyzer forced a delay until March 26, 2002.
4. Three H-46E aircraft were tested by HMX-1 at Quantico, VA the last week of March 2002. Five of the six engines would not produce rated power and three of the six were operating below the 95% power reject level. One low power engine had a 5% low offset in torque readings. Correction of this hidden torque fault would increase indicated power output thereby avoiding a false removal resulting in increased useful engine life.
5. The 4th MAW, Edwards AFB, CA, tested three additional H-53E aircraft in May of 2002. Seven of the ten engines tested had VGVs operating outside the acceptable bands. Four of the engines had no temperature margins at rated power but they all had acceptable temperature margin at 10% de-rate (380 SHP less per engine). Two out of three engines were not topped correctly preventing the engines from reaching the high point on four-point check. One engine, s/n 01816129, required 5 ½ turns in of the fuel control trim adjustment

to reach rated power at the 4th point on the nomograph check. Engine washes brought high-risk low CDP vs. Ng readings back into acceptable operation. Rigging the VGVs back to basic settings returned engine s/n 0816132 back into *deteriorated* from *high-risk* status. Users of the system stated that it provides data faster, monitors all three engines at the same time and presents data that is easy to interpret and understand abnormalities in the engine operation.

6. Kirkland AFB personnel used the test set on USAF H-53J/T64-100 engines both in parallel with the test cell and on the aircraft during July 15-19, 2002 with excellent results. Their technicians demonstrated ease in using the equipment and were impressed with the JETCAL2000® Analyzer as a new troubleshooting tool.
7. PMA 226 chose the equipment to be semi-permanently installed on an H-46E aircraft testing the new T58-16A Engine Reliability Improvement Program (ERIP) initial delivery engines. The data has established initial performance base lines and will track deterioration during initial engine operation. The H337PA-603 unit continues in trouble-free operation as a full time propulsion monitoring system.

3-2 ENGINE OPERATION INFORMATION

1. Initial testing demonstrated that JETCAL2000® Analyzer's accurate data recording capability reduces the window of uncertainty and greatly enhances the accuracy of installed engine performance testing and data interpretation. Engines certified by current engine performance verification techniques were shown by the test set to have many hidden problems. These flaws include often inaccurate and imprecise aircraft instrumentation, errors in the manual recording and manipulation of data and VGVs operating outside the acceptable band. Neither of the present techniques give criteria for evaluation of some hidden failure modes, e.g. slow Ng speed at power.
2. Test set data recording capability provides a selectable time interval (from 4 records per second to 256 seconds between records) for automatically storing time tagged history of installed engine operation. Single data points manually recorded by aircrews at four power settings are the only data points currently available. Test data has shown insufficient steady state operation for proper heat soak before aircrews record engine data leading to invalid answers on engine condition. This additional data from the test set has also demonstrated that some past assumptions about performance degradation are incorrect.
3. As an engine deteriorates, the various performance indicators do not necessarily change in a manner that is intuitively obvious. The complexity of installed engine performance and the shortcomings of current instrumentation and manual data manipulation make the JETCAL2000® Analyzer's data a prerequisite in verifying installed engine performance potential and diagnosing hidden discrepancies.
4. Testing has proven that the Howell's patented REDD DRP enables even the novice user to accurately determine engine performance potential. REDD also provides the detailed information required for troubleshooting so real problems can be found and repaired the first time.

3-3 CAPABILITIES VERIFIED

The JETCAL2000® Analyzer demonstrated its capability to provide maintenance personnel with test equipment that:

1. Does not add weight to mission aircraft-test set installed only when needed for engine test.
2. Identifies inaccurate engine instruments, reducing wrong maintenance decisions based on invalid information, e.g. engine removal.
3. Detects abnormal operation of internal engine parts as an indication of impending failure.
4. Provides a more powerful engine analysis capable of recommending repair action.
5. Provides an alternative to Remove and Replace (RandR) troubleshooting.
6. Reduces removal of serviceable parts.
7. Provides an accurate method to test and validate installed engine repairs.
8. Increases engine reliability and reduces O&S costs.

This Operational Test and Evaluation of the JETCAL2000® Analyzer portable engine test capability demonstrated its ability to provide the US Naval Aviation fleet with a comprehensive system that satisfies the current known requirements for fault isolation of engine components and directs maintenance actions based on results from the test data analysis.

The installed portable engine test set provided each of these capabilities in real time. First, cockpit instruments' accuracy is checked and validated against calibrated real time digital readings. Second, the test set display provides an immediate reference to a degraded engine performance condition. Third, analysis of the recorded data identifies abnormal or deteriorated components in a list of probable causes that can indicate impending failures of internal components. All three of these capabilities lead to decisive action to repair the identified faults. These repairs significantly enhance safety for the aircrew and the aircraft, and improve engine MTBR.

3-4 RECOMMENDATIONS

1. The H337PA-603 test set should be fielded and used following initial engine installation, at a regular interval, during pre-phase induction engine run, when a power check is failed and for installed evaluation prior to engine removal. The REDD concept has been proven to significantly improve knowledge of engine's performance potential and to identify abnormalities in engine modules needed for diagnostics. The output of the data analysis program provides a level of confidence in the performance potential of an installed engine not previously possible. It gives the user a way, under almost any conditions, to verify that he has a good engine. The REDD, using data from the JETCAL2000® Analyzer, works as a diagnostic system.
2. Maintenance manuals directing use of the JETCAL2000® Analyzer equipment and the REDD information in maintenance decisions are essential to successful fielding. In the case of a good engine verified by REDD, the decision is easy– fly it. But, when REDD identifies an unhealthy engine, the user needs something to tell him what is not working as it should. REDD lists probable cause for the abnormalities observed. If the mechanic still does not feel comfortable about what to fix, the recorded test data is in a format that can be quickly

transferred by modem or as an email attachment to an expert at any location—effectively bringing the expert to the user, anywhere, anytime. A database collection of run data from both test cell and installed engines has great management value. Test cell operators can compare their test results with installed results thereby locating and identifying things for the shop to look at that now shorten installed engine time.

3. The potential savings of finding hidden faults, making correct adjustment to engines, and reducing the window of uncertainty in interpreting test data has compelling ROI, greater than 30 to 1, and potential flight safety impact, e.g., for operating strong engines with low power because of under trim at the fuel control by 5 ½ turns. Implementing Stage II of this COSSI program offers the potential Navy and Marine users payback in less than two years and a reduction in propulsion O&S costs of more than 67 MILLION dollars.

Results from Stage I Prototype OT&E strongly support continuation to Stage II funding defined under the 845 Agreement i.e., 10 units @ $235,000 to the CH/MH-53E Maintenance specialists, and nine units @ $201,500 to the CH-46E Maintenance specialists.

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ABOUT THE AUTHOR

JAMES L. (BIG JIM) PETTIGREW is a graduate of Clemson University with a Master of Science Degree in Mechanical Engineering and attended Massachusetts Institute of Technology (MIT) as a special graduate student in Aeronautical Engineering. He is licensed as a Professional Engineer (LPE) in Texas, Ohio and South Carolina. He is currently employed as Director of Propulsion Diagnostics at Howell Instruments, Inc., Fort Worth, Texas.

Mr. Pettigrew retired from the US Air Force as a Lieutenant Colonel with twenty-eight years service. During his Air Force service, he was both a command pilot and a staff development engineer specializing in propulsion. He has flown as pilot and crew commander of B-47, B-52 and RF-4C combat aircraft. He holds civil aviation airline pilot and flight instructor ratings and has logged more than 11,000 flight hours.

He served as an engineer for 16 years before retiring from Wright-Patterson AFB, OH as the Deputy Director of Flight Systems Engineering for USAF Aeronautical Systems Division. While assigned to Headquarters, Strategic Air Command as command propulsion engineer, Jim developed and wrote the documents to implement the J57, TF33, and TF30 Engine Condition Monitoring Programs (ECMP). The ECMP was credited with saving over two million dollars per month and cutting in-flight shutdowns in half. He was recognized by the Air Force Association with a Scientific Achievement Award this work. He is a twenty-nine-year active member of Society of Automotive Engineers (SAE) Committee E-32 on Gas Turbine Engine Monitoring.

Mr. Pettigrew has been with Howell Instruments since 1984 and has developed the requirements for the Engine Performance Assurance Monitoring System (EPAMS), the Portable Engine Analyzer Test Set (PEATS), and the JETCAL2000® Analyzer. He managed the EPAMS program used by the Navy for mission profile definition on T58, T64, TF34 AND J85 engines and the Commercial Operations and Support Savings Initiative (COSSI) Marine Corps program to adapt JETCAL2000® Analyzer (portable test cell capability) for engines installed on H-46 and H-53 Aircraft. Since 1999, He has been a member of the SAE A-1E committee on engine test cells.

He has planned and led multiple Operation Test and Evaluation programs of Howell test equipment. His extensive knowledge of thermodynamics and in depth analyses of engine performance and flight data has assured quality performance on each test system. He has extensive experience in engine on-wing/test cell data acquisition, interpretation, and diagnostic analysis of engine components. He has planned and taught classes and trained customers in the use of acquired engine performance data for accurate diagnostic results. He used knowledge engineering methods to capture expert field experience needed to produce advanced artificial intelligence (AI) capability in a Data Reduction Program (DRP) that outputs unique information on turbine engine internal condition. Mr. Pettigrew holds Patent Number 5,018,069 on this Referred Engine Diagnostic Data (REDD) methodology. The unique REDD DRP output information allows novice personnel to be capable experts in assessing turbine engine performance capability and in diagnosing and isolating internal turbine engine faults.

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APPENDIX A —TEST RESULTS

4-0 DETAILED TEST RESULTS, H337PA-603 JETCAL2000® ANALYZER

Detailed results from the operational test and evaluation (OT&E) of the H337PA-603 JETCAL2000® Analyzer capabilities, January 28, 2003

4-1 BACKGROUND

4-1.1 Test Authority And Coordination

This OT&E test was conducted under a Commercial Operations and Support Initiative (COSSI) 845 agreement, M67854-97-C-2117, Effective 01 Sep 1997, Authority: 10 U. S. C. 2371, pursuant to and under U.S. Federal law between The United States of America, hereinafter called the Government, represented by the MARCORSYSCOM, and Howell Instruments, Inc. Document was accepted for MARCORSYSCOM by Mr. Edward J. Stolark, Director Contracts and was administered by Mr. Stephen L. Riffe, Agreements Officer.

The Cherry Point Naval Aviation Depot (NADEP) Executive Officer, Colonel Robert N, Leavitt, represented his DOD organization in the original Commercial O&S Savings Initiative (COSSI) proposal. The MARCORSYSCOM Program Manager at the NADEP was Logistics/Research and Engineering Coordinator, Marine Lieutenant Colonel Lewis J. Cipriani, assisted by Marine Staff Sergeant D. D. Carpenter, (252) 464-9457, Assistant Research and Engineering Logistics Officer. The Howell Instruments, Inc. Project Engineer was Mr. James L. Pettigrew, LPE.

Lieutenant Colonel Cipriani was reassigned as NADEP Quality Officer before the JETCAL hardware was delivered. He assigned Brantley Garner, (252) 464-7327 and J. D. Thatch, (252) 464-8161, of Cherry Point Aviation Depot Division 4.8.7.5 to lead the test phase of the COSSI JETCAL2000® Analyzer Project. They completed a plan to conduct the evaluation per the 845 Agreement Statement Of Work (SOW) between Howell Instruments, Inc. and Marine Corps System Command in a timely manner. Support equipment engineer, Mr. John Thatch, was prime Point Of Contact (POC) for OTE testing at NADEP and other locations.

4-1.2 No Aircraft Modifications Required

Test Set installation requires electrical interface with aircraft instrumentation system through "Y" cables with standard aviation connectors and fluid systems with standard AN-type hose fittings. Original configuration is restored when the test set is removed. No permanent airframe modification is required. Additional weight is added to the aircraft only for a maintenance test flight. Operational aircraft do not incur a weight penalty when the engines have been certified using the portable turbine engine test set.

4-1.3 Operational Test Procedures

The H337PA-603, JETCAL2000® Analyzer requires flying the aircraft to allow the altitude power lapse to reduce the engine power output below the transmission limit for testing at maximum engine capability. When this altitude is reached, one engine or more is operated at reduced power while the engine under test is operated at maximum power. A three or four point power check per Naval Air Training and Operating Program Standardization (NATOPS) offers an alternative to operating at maximum power. Stable operation and thermal heat soak

are required at each test point for accurate data. These power settings are high enough to require flight at altitude to lower engine output below transmission limits. Flight clearances were issued for the H-46 and H-53 aircraft for maintenance test flights with the JETCAL2000® Analyzer installed.

The NADEP Flight Test Unit personnel were to install and use the JETCAL2000® Analyzer test set on all test flights where engine performance was being evaluated. The flights are flown using standard NATOP procedures and limitations with the Flight Test Checklist from APPENDIX A in the JETCAL2000® Analyzer operator's manual. In addition to the four point performance checks, power settings across the normal engine operating range are used where practical. These power settings provide data for graphs across the engine's operating range thereby allowing verification of each type's performance model.

Checklists were provided to flight line personnel for installing and removing the JETCAL2000® Analyzer. These check lists identify to the appropriate Quality Control specialist each area where equipment is added. Quality Control then uses the installation procedures from the JETCAL2000® Analyzer operator's manual and appropriate Navy manuals to verify flight worthiness of the aircraft after JETCAL installation and removal.

Using aircraft power, test pilots, crew chiefs or Quality Control personnel can analyze the engine test data on the aircraft using the JETCAL. The control unit can also be moved to an office where it can operate on 110 VAC. Floppy disk capability allows the test data to be moved to an office computer. With the Referred Engine Diagnostic Data (REDD) analysis software program installed, the test data can be viewed and printed. From the PC, the data can be sent by modem or email to another location for expert help.

4-1.4 OT&E Validation Objectives

Howell Instruments reviewed Navy requirements for testing installed engines. The resulting design offers a unique portable airborne instrumentation package with complete on-wing test instrumentation and diagnostic capability that provides specific repair recommendations.

Data collected from the engine test set will provide improved methods of engine performance analysis. The JETCAL2000® Analyzer brings to the fleet an accurate and comprehensive system to carry the H-53 and H-46 maintenance operations well into the 21st century, in line with the Automated Maintenance Environment (AME).

4-1.5 Test Set Capabilities

As an aid to engine maintenance, the JETCAL2000® Analyzer test set has the following capabilities:

1. Provides accurate instrumentation traceable to the National Institute of Standards and Technology (NIST) to verify cockpit instrument accuracy.
2. Records data from an installed engine with test cell accuracy.
3. Provides real-time performance metrics to aid in determining optimum settings during engine tuning.
4. Diagnostic data displays enabling the user to readily identify engine abnormalities including abnormal performance in the compressor, burner section or turbine sections of the engine.

5. Provides a rational alternative to the "parts-changing" method currently in place for troubleshooting engines, reducing O&S costs.
6. Reduces the window of uncertainty associated with recording cockpit instrument data.
7. Reduces the number of good engines prematurely removed for repair.
8. Verifies engine performance and effects of maintenance actions on engine performance by having before-and-after diagnostic data available
9. Provides printed engine performance history with a maintenance audit trail.
10. Establishes a performance baseline for individual engines and engine types that can be utilized in a central database.
11. Calculates torque (Q) values using measured engine parameters to get an expected torque that the engine should produce from the thermodynamic engine model. Calculated thermodynamic torque values give an independent reference that can be used to check the aircraft torque indicating system for probable error.
12. Informs operators of the amount of engine temperature and speed margin remaining.
13. Shows how well the aircrew stabilized and heat soaked the engine before recording power check data.

The JETCAL2000® Analyzer test set electronically senses and records, using operator selected recording routines, engine operating data into a solid-state one-gigabyte hard drive. The operator can also elect to and select recording of portions of engine data on demand. The visual screen displays digital instrument values in real-time. The instrument check mode allows the operator to enter the cockpit instrument readings along with the JETCAL2000® Analyzer values as a record of their accuracy.

Use of the test sets data analysis capability will reduce removal of Ready For Issue (RFI) components, and reduce maintenance man-hours and flight hours for removal and testing of RFI engines rejected by invalid cockpit instrumentation, and give early warning of imminent failures which will reduce the potential for loss of aircraft and lives when corrected.

5-0 REFERRED ENGINE DIAGNOSTIC DATA (REDD)

Development of Referred Engine Diagnostic Data (REDD) requires the following steps:

1. Collect performance data from an operating engine.
2. Normalize or correct the engine data to standard day sea level equivalent values.
3. Compare actual operating data to an expected performance value from a model. The REDD values are presented as a dependent and independent variable pair, e.g. GT : Ng. GT (Gas Temperature) is dependent REDD variable. Ng (gas generator speed) is used to get the expected temperature from the model. The REDD value is the difference between the model values at the Ng speed and the indicated value.
4. Classify the magnitude of REDD deviation between actual data and expected performance as either NORMAL, DETERIORATED OR HIGH RISK.
5. Identify REDD parameters with engine sections. Abnormal values then point to the section of the engine with the abnormal performance.

REDD values will be near zero for normally operating engines and increase as an engine deteriorates. Repairs that correct the indicated problem will cause a lower REDD value.

The JETCAL test set provides an improved method for testing the turbo shaft engine while installed in the aircraft. It checks cockpit instruments, records data, and analyzes performance with a diagnostics output. Howell's patented REDD Data Reduction Program (DRP) enables even the novice user to determine performance potential. REDD also provides the detailed information required for troubleshooting so that real problems can be found and fixed the first time. The diagnostic feature cuts the number of flights needed to verify engine performance and airworthiness for fleet operations.

6-0 REDD EXAMPLE

REDD output formats include:

- Possible Faults
- High Power Performance Summary
- Engine Performance Diagram
- High Power Performance Chart
- Maximum Power Check Records
- XY Graphs of Operating Data
- Individual Data Records

HMH769's aircraft 162012, number 2 engine, s/n 0269757, was changed based on the data presented by the JETCAL2000® Analyzer from a May 23, 2002 test. Engine s/n 269551 was installed as a replacement. The test set was installed in the single engine configuration for a test of the new engine on the June 5, 2002. REDD output data products follow for the rejected engine and the replacement engine.

The first engine was operating with a compressor running 1.454 ratios below model value of 13.65 ratios. It would operate 30 °C above the cockpit limit at rated power and 14 °C below the limit at the 90% reject power. The nomograph represented by the dashed line on the gas temperature (T5) versus torque graphs is set for reject at 90% percent rated power. This engine showed acceptable GT margin on the nomograph by 10 °C to 15 °C.

Time plots show that the pilot reduced and reapplied power by 8 percent during the one-minute test. As temperature lags gas generator (Ng) speed and torque by 5 to 10 seconds, depending on the size of the change, the amount of margin will be higher than if the engine is allowed to reach thermal equilibrium. Most of the temperature points in the max power cluster on the GT vs. Q graph are at reduced power. A pilot will only record one data point for each parameter at a time during a normal single check. Unstable operation (changes in power) introduces incorrect data into the decision process. Sensor time delay can incorrectly pair data for performance evaluation. The variation can cause a good engine to be judged faulty and cause a faulty engine to be judged airworthy.

6-1 REJECTED ENGINE EXAMPLE

Possible Faults
CH-53E T64-416 REFERRED ENGINE DIAGNOSTIC DATA (REDD)
ACFT # 162012, ENg# 0269757, Pos 2, 23-May-2002 13:09:45
Location: KEDW FUEL JP-8 TOTAL HRS 2420.19
Troubleshooting Data
Stability Filter - N, Ngc = 98.0 to 106.0 %RPM, Ignore Bleeds - Y
Used 20 records in calculations.

****
VGV out of band - VGV settings change both compressor and turbine performance. Look at VGV vs Ngc graph. Correct and refly test flight.
Fuel control trim (if applicable) set low - indicated power check torque is less than target value with Ng and T5 less than limits.

CHECK THE FOLLOWING:
- Low power at gas temperature limit.
- Compressor dirty.
- Bleed band leaking.
- Anti-ice on or customer air leaking.
- FOD or blade erosion in compressor.
- Combustor section damaged.
- Open combustor chamber drain.
- Starting fuel solenoid fails to close.

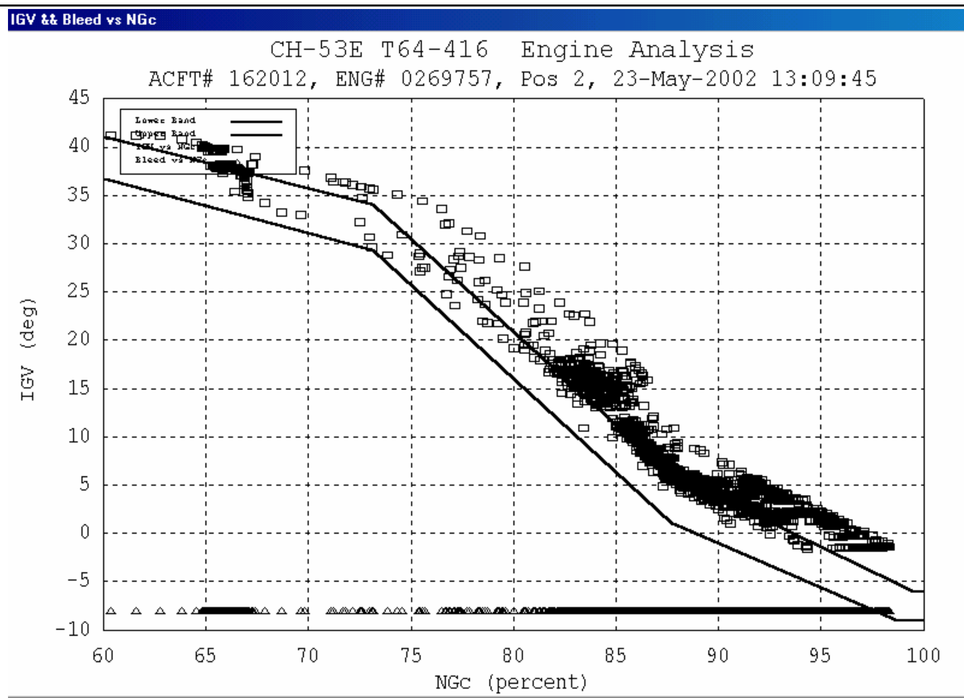


Figure 6-1-1 VGV vs. Ngc, CH-53E

VGV sticking. Note the speed change with constant VGV values.

NOTE: Several flat lines of VGV position while Ngc changes.

```
             High Power Performance Summary,  H105G-9 ver 2.19
             CH-53E T64-416   REFERRED ENGINE DIAGNOSTIC DATA (REDD)
   At RATED (4390 SHP, 130.7 %Q), Model is 97.8 %Ng, T5=746 °C , CDPr=13.528,
            WF=1969 pph, SFC=0.448 pph/hp, T4.1=1237 °C , WA=27.8 pps
----------------------------------------------------------------------
     ENGINE STATUS: VGV out of band - HPPS diagnostics may not be reliable.

             ACFT # 162012, ENg# 0269757, Pos 2, 23-May-2002 13:09:45
                  Location: KEDW  FUEL JP-8  TOTAL HRS 2420.19
         Engine will produce SDAY RATED power at  98.8% Ng and 803 °C  T5
                Turbine Eff= 84.5, T4.1c= 1202 °C, WAc = 28.0 pps
-----------------------------------------------------------------------------
EXPECTED<----------ACCEPTABLE--------------->|<----DETERIORATED--->:HIRISK
                                                                   ^
|____________________________________________|6_______7__________P_:I__
|           Compressor Performance           |                     ^

|_________T______F__2_5_________________4____|______________________:___
|        Gas Gen. Turbine Performance        |                     ^

|______________MS____________1W_______G______|______________________:E__
|               Overall Performance          |                     ^

     NOTE: Points right of '^' not scaled.  Used 20 records in calculations.
        Stability Filter - N, Ngc = 98.0 to 106.0 %RPM, Ignore Bleeds - Y

                           STANDARD DAY CORRECTED DATA
    1 T5:Ng        (+/-50 °C) 33          5 Ng:Q        (+/-2.0%) 1.0
    2 Q:Ng         (+/-16.0%) -7.3       *E T5:Q       (+/-30 °C) 58
                                         *6 CDPr:Q       (+/-1.0) -1.023
   *P CDPr:Ng        (+/-1.0) -1.454     *7 WF/CDPr:Q (+/-14.934) 18.2
    4 WF/CDPr:Ng  (+/-14.934) 13.5
   *I IGV:Ng     (+/-2.0 deg) 5.1         G T5:WF      (+/-50 °C) 42
       Delta @ 98.0% Ngc                  F Q:WF       (+/-12.0%) -4.6
    W T5:Ng        (+/-50 °C) 33          T Ng:WF        (+/-1.6) 0.4

                                          S PTI:CDPr   (+/-10.0%) -3.6
                                            Bleeds:  closed
                                          Margins @ SDAY/SL 90.0% RATED
    %Rated Q @ T5 limit (>90.0%)   93.1     T5c     (>+0 °C +71)   14
    %Rated Q @ Ng limit (>90.0%)   106.1    Ngc    (>+0.0% +3.9)   2.9
    SFCc (Ref:  0.448 pph/hp) 0.467
----------------------------------------------------------------------------
       Power Check Results (INDICATED)
   *Q man  (110.1 %)= 109.5 [3727 SHP]    M FP (375 to 575 psia)   509
     OAT  18.7  Ng  98.8  PA  3557           Vibs(ips)  @98.0%Ng  Peak
     T5    800  Q/SET 0.995                 VNg  (<1.80)  0.58    0.58
    T5 Max 773.0  Ng Max 100.0              VNF  (<1.80)  0.27    0.27
----------------------------------------------------------------------------
    c  - REDD Data at Standard-Day Sea Level Conditions.
    *  - Indicates Abnormal Engine Performance.
 ****  - Value out of Expected Range, Check Instrumentation.
 Comments\Actions Taken
  NO. 1-TSO
  NO.2-TSN- HIGH TIME
  NO.3-TSO
```

Figure 6-1-2. High Power Performance Summary, CH-53E

The alphanumeric symbols are defined in the standard day corrected data. Acceptable bands are in parentheses.

NOTE: "I" is in the HIRISK area.

Maximum Power Performance
CH-53E T64-416 REFERRED ENGINE DIAGNOSTIC DATA (REDD)
ACFT # 162012, ENg# 0269757, Pos 2, 23-May-2002 13:09:45
Location: KEDW FUEL JP-8 TOTAL HRS 2420.19

Power Check Records
20 records met filter requirements.
Qc >= QRc - 6.0 %
Stability Filter - N, Ngc = 98.0 to 106.0 %RPM, Ignore Bleeds - Y

			SEA LEVEL		STD DAY		
		IND.	OBS.	MIN/MAX	OBS.	SPEC.	MARGIN
PAMB	(psia)	12.90					
OAT	(°C)	18.7					
Q	(%)	109.5	124.7	125.4/	*125.5	126.1	-0.6
SHP	(hp)	3727	4245	4266 /	*4217	4239	-21
Ng	(%RPM)	98.8		/100.0	98.1	99.4	1.2
T5	(°C)	800		/773	*786	760	-26
WF	(pph)	1734	1975		1959		

		IND.	OBS.	MODEL	REDD	
CDPr			12.194	13.647	-1.454	CDPr:Ng
T4.1	(°C)	1222	1202	1208	-6	T4.1:Q
SFC	(pph/hp)	0.465	0.465	0.446	0.018	SFC:Q

This engine does NOT meet all specification limits.

Time sec	Ng %RPM	T5 °C	Q %	SET %	NF %RPM	Qc %	OAT °C	PA ft	T4.1 °C	Q/SET
---average--										
3380	98.8	800	109.5	110.1	101.3	125.5	18.7	3557	1222	0.995
----span----										
49	0.4	14	3.4	1.4	0.7	3.5	0.6	140	14	0.028
3364	98.7	801	111.2	110.4	101.1	127.3	18.6	3560	1222	1.008
3365	98.7	802	111.0	110.2	101.1	127.2	18.6	3590	1226	1.007
3368	98.7	803	110.6	110.4	101.2	126.8	18.4	3570	1221	1.002
3401	98.8	801	110.4	109.8	101.3	126.7	18.9	3590	1220	1.006
3404	98.7	804	109.9	109.6	101.4	126.2	19.0	3590	1222	1.003
3402	98.9	803	109.9	109.7	101.4	126.1	19.0	3570	1226	1.002
3361	98.7	798	110.2	110.3	101.1	126.1	18.7	3550	1223	0.999
3355	98.9	792	110.7	110.9	100.9	125.9	18.8	3450	1228	0.999
3398	98.8	798	109.2	109.5	101.6	125.7	18.8	3590	1225	0.997
3356	99.0	796	109.7	110.1	101.4	125.6	18.8	3500	1222	0.996
3363	98.7	801	109.6	110.3	101.1	125.4	18.7	3550	1226	0.993
3399	98.7	799	109.0	109.6	101.5	125.3	18.9	3580	1220	0.995
3396	98.7	790	109.3	110.0	101.3	125.3	18.8	3550	1223	0.993
3367	98.7	803	109.1	110.3	101.2	125.1	18.5	3570	1215	0.989
3366	98.7	802	109.0	110.3	101.2	124.9	18.5	3570	1221	0.988
3362	98.7	799	109.2	110.3	101.1	124.9	18.7	3550	1226	0.990
3400	98.7	800	108.3	109.7	101.4	124.3	18.9	3570	1216	0.987
3369	98.6	802	108.2	110.4	101.3	124.0	18.4	3530	1218	0.980
3403	98.8	804	107.8	109.4	101.6	124.0	19.0	3570	1220	0.985
3397	98.9	795	107.8	109.8	101.5	123.7	18.8	3540	1229	0.981

Figure 6-1-3. Maximum Power Performance Summary, CH-53E

Maximum Power Performance takes flight recorded data and normalizes information to test cell criteria. Top 20 highest standard day sea level power (Qc) records are used.

NOTE: * denotes failure.

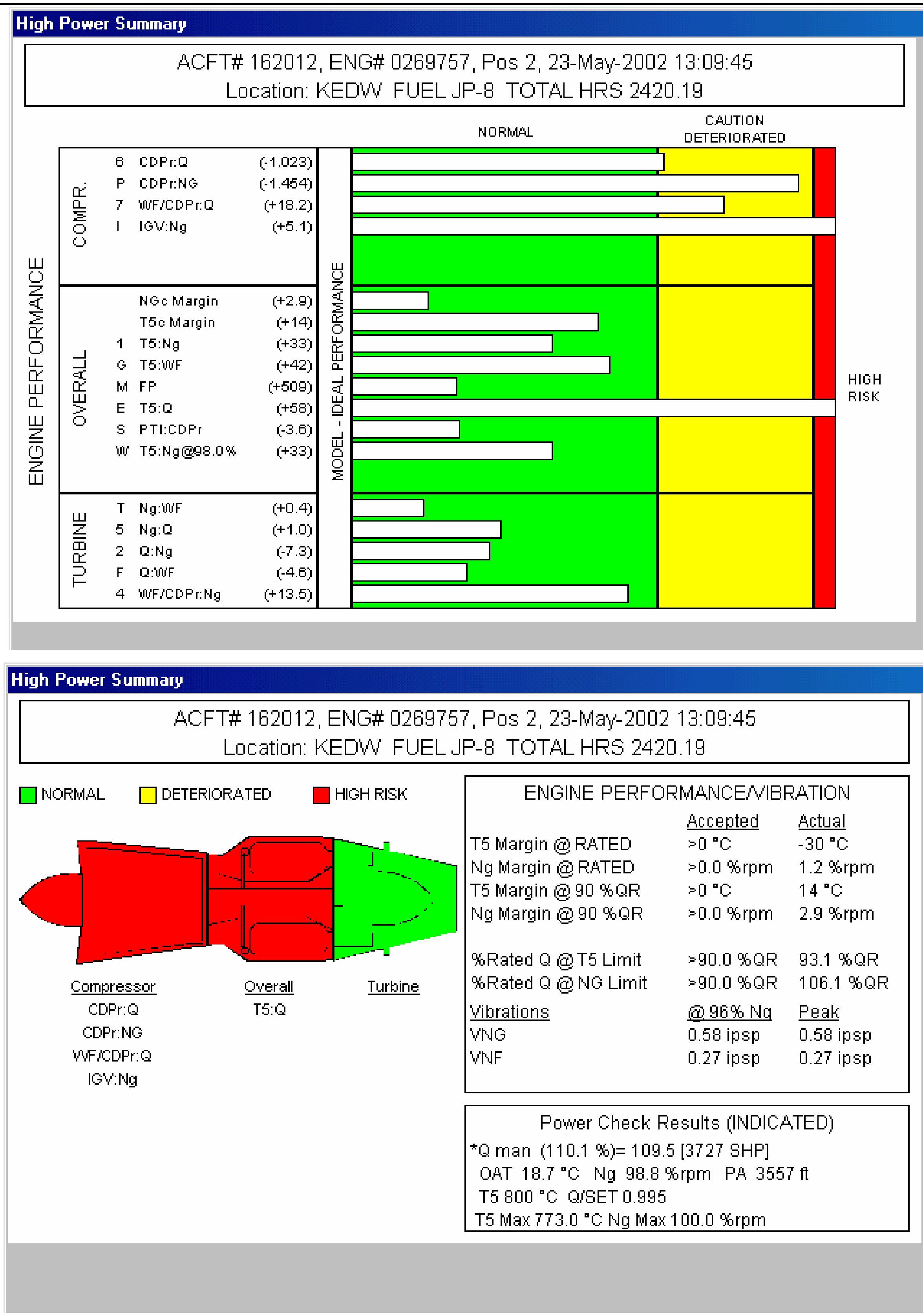


Figure 6-1-4. Graphic Presentation of High Power Summary Data, CH-53E

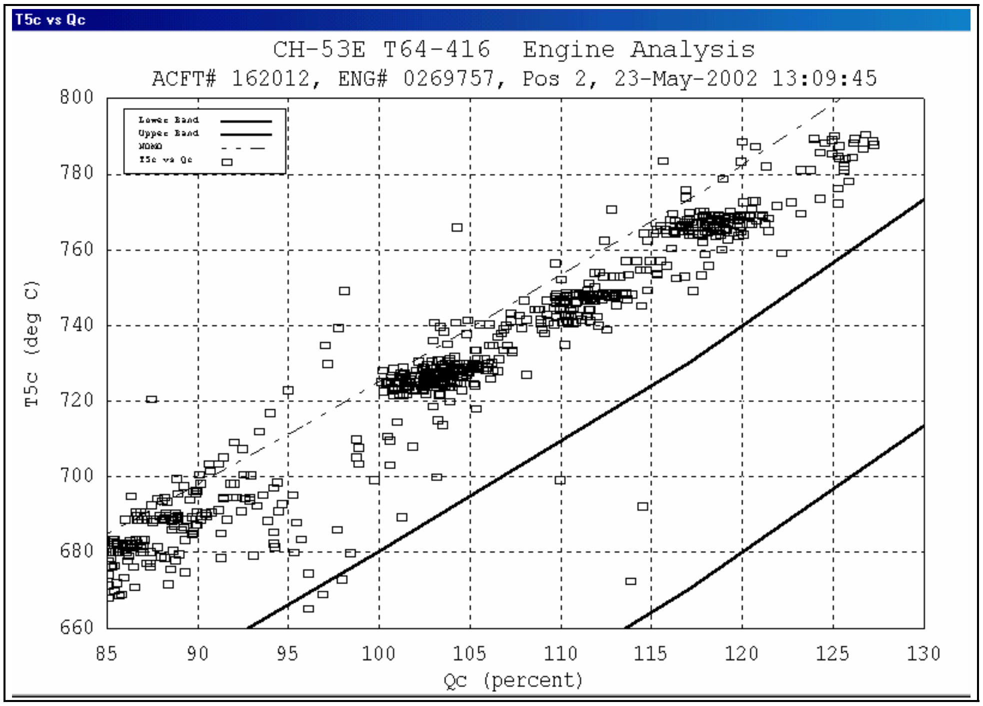


Figure 6-1-5. Temperature vs. Torque, CH-53E

Note the cold T5 reading at max power on the T5vs Ng graph above.
Note from the power check record data, selected T5 had 14 °C spread

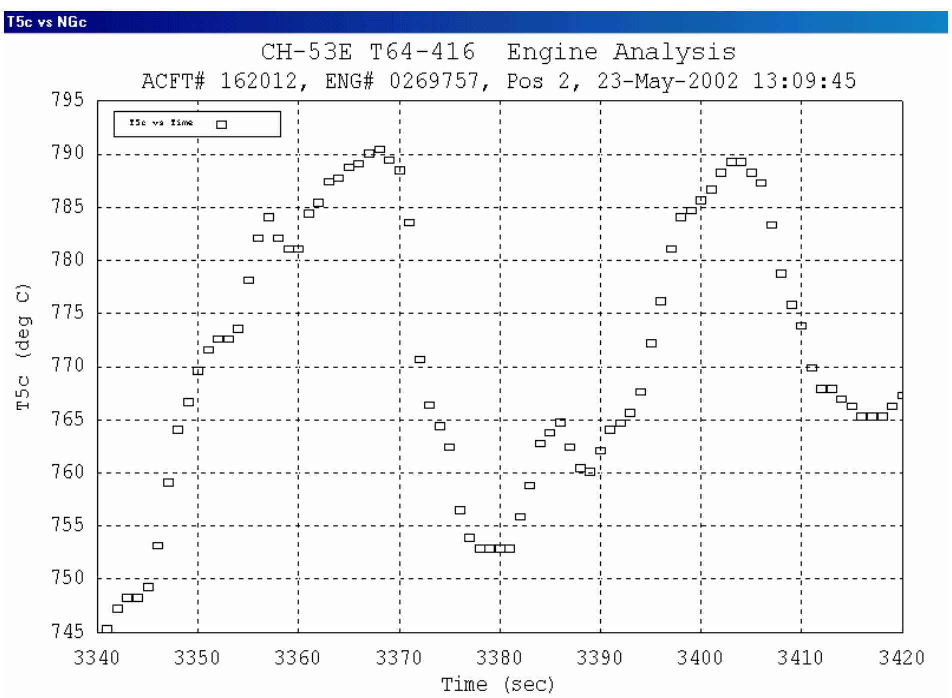


Figure 6-1-6. Temperature vs. Time, CH-53E

Temperature change with time at power check point 100 seconds.

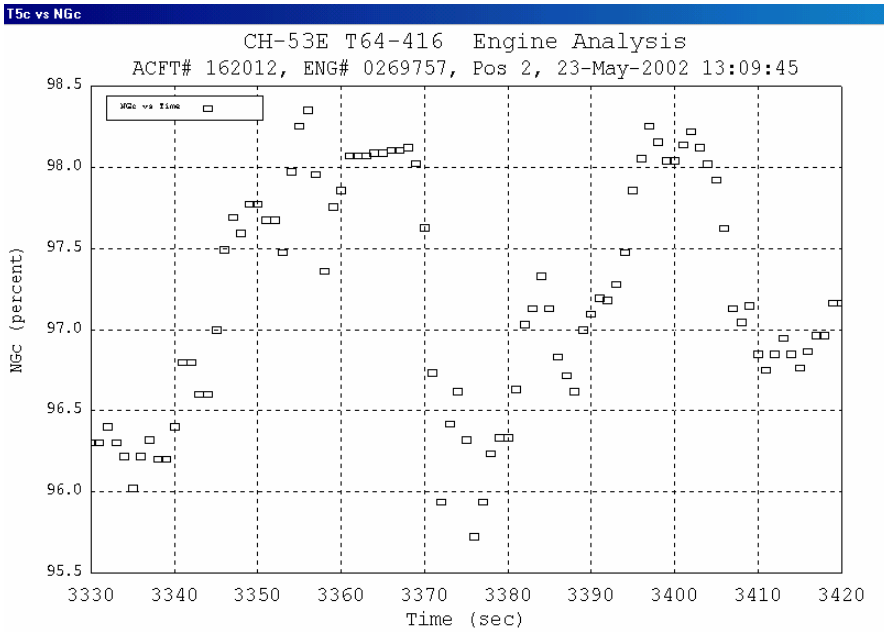


Figure 6-1-7. Ngc vs. Time Profile Graph, CH-53E

Each of these profile graphs show that all engine parameters have the same pattern. Without multiple data sources, it is easy to call the variation "data scatter" instead of "varying engine power." The time lines show reading delays. The reading and recording of only one parameter at a time will increase the potential to erroneously judge either a faulty engine to be good or a good engine faulty.

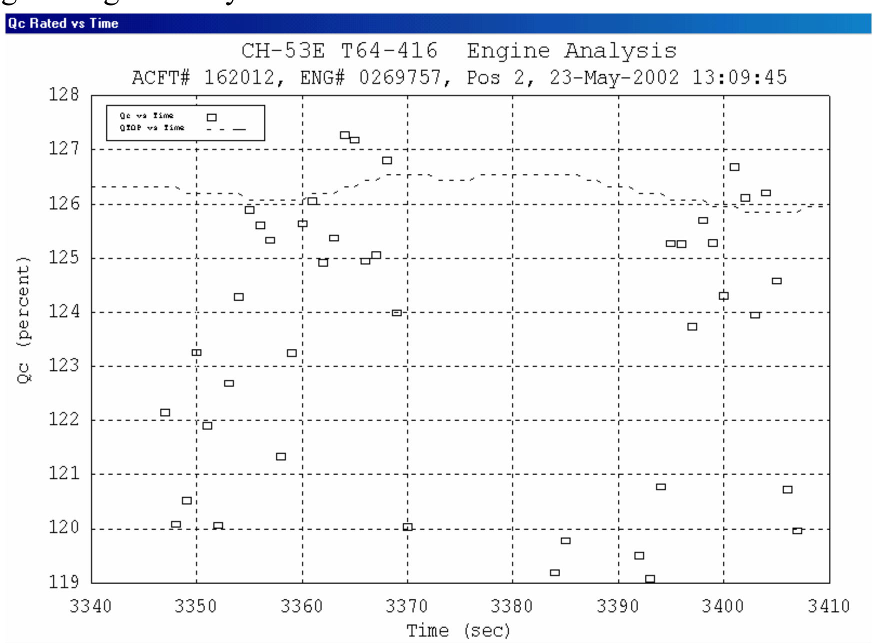


Figure 6-1-8. Torque vs. Time, CH-53E

Note an 8 % torque or 269 SHP variation in 70 seconds. Lack of thermal equilibrium gave this engine a better evaluation than it deserved. If the stability filter is selected, the data

shows the engine is rejected at less than 90 % rated power. Setting the VGVs would have kept the engine on wing.

6-2 REPLACEMENT ENGINE–REDD EXAMPLE

The replacement engine for HMH769's aircraft 162012, number 2 position, was s/n 269551. The JETCAL2000® Analyzer was installed in the single engine configuration for a test of the new engine on June 5th 2002. The REDD data products follow for the replacement engine.

The second engine is compared to how the first engine was operating. The 2nd compressor operated 1.005 below the model compared to the 1st at 1.454 ratios below model value of 13.65 ratios. It would operate 17 °C below the limit compared to 30 °C above the cockpit limit at rated power and 60 °C compared to 14 °C below the limit at the 90% de-rated power. The nomograph represented by the dashed line on the gas temperature (T5) versus torque graph is set for reject at 90% percent rated power. The engine shows acceptable GT margin on the nomograph by 10 °C to 15 °C. The aircrew did not hold power steady for thermal equilibrium to be achieved. If stable data is used, the engine has a negative margin at 90% power. T4.1 for the replacement engine was 23 °C above expected while the removed engine was 6 °C below. Less compressor work uses less fuel therefore cooler T4.1.

6-3 REJECTED ENGINE EXAMPLE

```
                    Possible Faults
  CH-53E T64-416   REFERRED ENGINE DIAGNOSTIC DATA (REDD)
  ACFT # 162012, ENg# 269551, Pos 2,  5-Jun-2002 17:47:05
        Location: KEDW  FUEL JP-8  TOTAL HRS 735.09

                  Troubleshooting Data
  Stability Filter - N, Ngc = 96.0 to 106.0 %RPM, Ignore Bleeds - Y
               Used 31 records in calculations.

******************************************************************************

******************************************************************************
IGV out of band - IGV settings change both compressor and turbine
performance.  Look at IGV vs Ngc graph.  Correct and refly test flight.


Power check not completed on the limiter (if applicable) - Power Check
Record's T5 varies by 43 °C.

  CHECK THE FOLLOWING:
    Max. power check not performed correctly.
    Fuel control max. power trim adjustment.
```

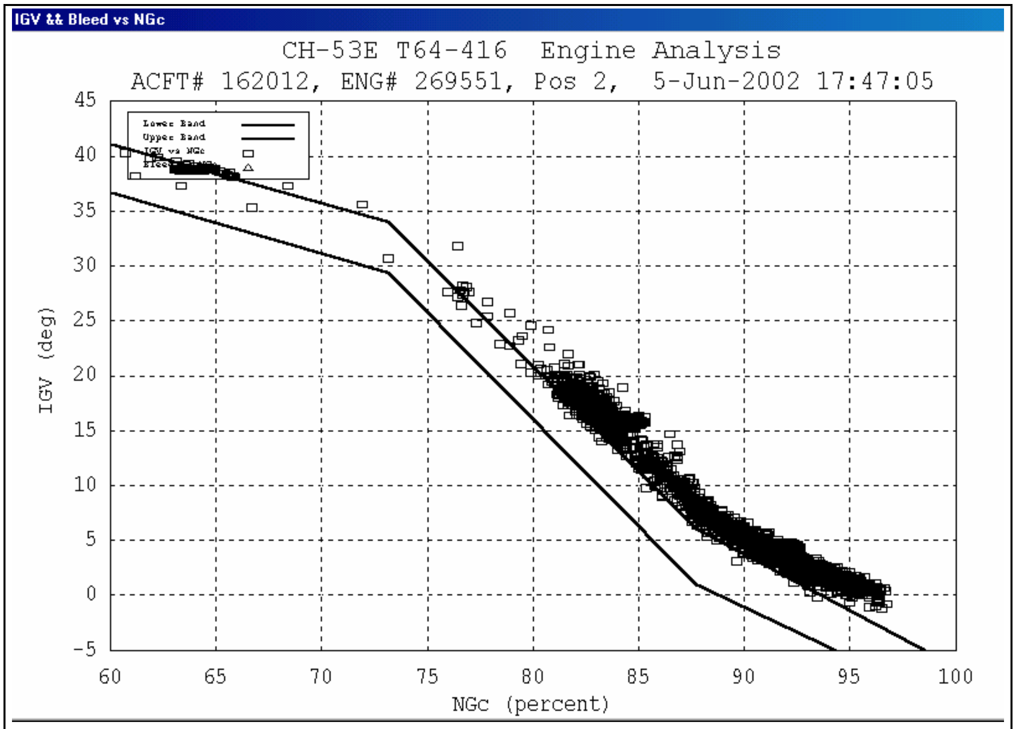


Figure 6-3-1. IGV vs. Ngc, CH-53E

VGV adjustment on replacement engine. Outside the band but no evidence of sticking as seen on the removed engine.

```
              High Power Performance Summary,  H105G-9 ver 2.19
           CH-53E T64-416   REFERRED ENGINE DIAGNOSTIC DATA (REDD)
    At RATED (4390 SHP, 130.7 %Q), Model is 97.8 %Ng, T5=746 °C, CDPr=13.528,
            WF=1969 pph, SFC=0.448 pph/hp, T4.1=1237 °C, WA=27.8 pps
-----------------------------------------------------------------------------
     ENGINE STATUS: IGV out of band - HPPS diagnostics may not be reliable.

           ACFT # 162012, ENg# 269551, Pos 2,  5-Jun-2002 17:47:05
                 Location: KEDW  FUEL JP-8  TOTAL HRS 735.09
       Engine will produce SDAY RATED power at  99.0% Ng and 756 °C T5
              Turbine Eff= 82.6, T4.1c= 1165 °C, WAc= 26.8 pps
-----------------------------------------------------------------------------
EXPECTED<----------ACCEPTABLE--------------->|<----DETERIORATED--->:HIRISK
                                                                   ^
|________________________6__________________|______P7_____________:I__
|           Compressor Performance          |                      ^

|T_______________________52________F______4__|____________________:___
|        Gas Gen. Turbine Performance       |                      ^

|S______________1EGW__M_____________________|_____________________:___
|            Overall Performance            |                      ^

     NOTE: Points right of '^' not scaled.  Used 31 records in calculations.
        Stability Filter - N, Ngc = 96.0 to 106.0 %RPM, Ignore Bleeds - Y

                        STANDARD DAY CORRECTED DATA
    1 T5:Ng        (+/-50 °C) -18         5 Ng:Q        (+/-2.0%) 1.2
    2 Q:Ng         (+/-16.0%) -9.5        E T5:Q       (+/-30 °C) 11
                                          6 CDPr:Q       (+/-1.0) -0.562
   *P CDPr:Ng        (+/-1.0) -1.164     *7 WF/CDPr:Q (+/-14.934) 17.6
    4 WF/CDPr:Ng  (+/-14.934) 14.0
   *I IGV:Ng     (+/-2.0 deg) 4.8         G T5:WF      (+/-50 °C) -18
       Delta @ 96.0% Ngc                  F Q:WF       (+/-12.0%) -9.5
    W T5:Ng        (+/-50 °C) -18         T Ng:WF        (+/-1.6) -0.0

                                          S PTI:CDPr   (+/-10.0%) -0.3
                                            Bleeds:  closed
                                          Margins @ SDAY/SL 90.0% RATED
    %Rated Q @ T5 limit (>90.0%)   103.4    T5c     (>+0 °C +71)   60
    %Rated Q @ Ng limit (>90.0%)   105.2    Ngc    (>+0.0% +3.9)   2.8
    SFCc (Ref:  0.448 pph/hp) 0.483
-----------------------------------------------------------------------------
      Power Check Results (INDICATED)
    Q man  (96.6 %)= 102.2 [3425 SHP]     M FP (338 to 538 psia)   488
     OAT  35.5  Ng  99.6  PA  3746           Vibs(ips)  @96.0%Ng  Peak
     T5    773  Q/SET 1.058                 VNg  (<1.80)  0.00    0.00
    T5 Max 773.0  Ng Max 100.0              VNF  (<1.80)  0.00    0.00
-----------------------------------------------------------------------------
    c  - REDD Data at Standard-Day Sea Level Conditions.
    *  - Indicates Abnormal Engine Performance.
 ****  - Value out of Expected Range, Check Instrumentation.
 Comments\Actions Taken
  tsn 1595.9 hrs tso 732.9
```

Figure 6-3-2 High Power Performance Summary

The alpha-numeric symbols are defined in the standard day corrected data. Acceptable bands are in parentheses. NOTE: "I" us in the HIRISK area.

Maximum Power Performance
CH-53E T64-416 REFERRED ENGINE DIAGNOSTIC DATA (REDD)
ACFT# 162012, ENg# 269551, Pos 2, 5-Jun-2002 17:47:05
Location: KEDW FUEL JP-8 TOTAL HRS 735.09

Power Check Records
Used top 20 (highest Qc) of 30 records that met filter requirements.
Qc >= QRc - 6.0 %
Stability Filter - N, Ngc = 96.0 to 106.0 %RPM, Ignore Bleeds - Y

			SEA LEVEL		STD DAY		
		IND.	OBS.	MIN/MAX	OBS.	SPEC.	MARGIN
PAMB	(psia)	12.82					
OAT	(°C)	35.5					
Q	(%)	102.2	117.2	110.9/	112.9	107.0	6.0
SHP	(hp)	3425	3927	3718 /	3795	3594	201
Ng	(%RPM)	99.6		/100.0	96.3	96.6	0.4
T5	(°C)	773		/773	703	704	0
WF	(pph)	1643	1883		1804		

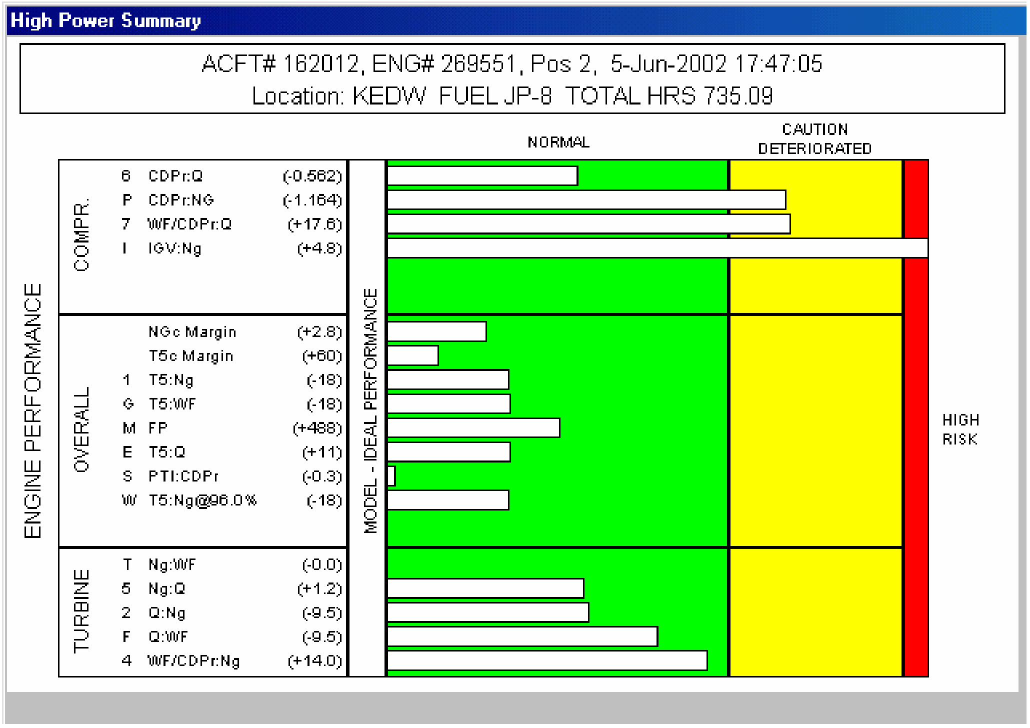
		IND.	OBS.	MODEL	REDD	
CDPr			11.811	12.816	-1.005	CDPr:Ng
T4.1	(°C)	1274	1165	1142	23	T4.1:Q
SFC	(pph/hp)	0.479	0.476	0.446	0.029	SFC:Q

This engine meets all specification limits.

Time sec	Ng %RPM	T5 °C	Q %	SET %	NF %RPM	Qc %	OAT °C	PA ft	T4.1 °C	Q/SET
---average--										
2616	99.6	773	102.2	96.6	99.7	112.9	35.5	3746	1274	1.058
----span----										
2045	2.3	43	12.5	3.7	1.8	7.7	12.3	2160	85	0.155
3197	99.2	780	101.6	96.9	100.3	116.7	31.6	4460	1267	1.049
3161	99.0	772	100.7	97.0	100.2	115.7	31.5	4490	1255	1.039
3162	99.2	777	100.6	97.0	100.2	115.6	31.5	4490	1257	1.038
3229	99.0	784	101.1	97.6	99.5	115.4	31.5	4510	1263	1.036
3230	99.0	786	100.5	97.3	99.8	115.1	31.5	4500	1264	1.033
3218	99.0	780	100.3	97.1	99.8	114.7	31.8	4490	1259	1.033
3198	98.9	784	99.1	96.7	100.5	114.0	31.6	4450	1252	1.024
3228	99.0	781	99.8	97.5	99.6	113.9	31.6	4480	1247	1.024
3196	98.9	775	99.6	97.3	99.8	113.9	31.6	4470	1256	1.023
3217	98.8	776	99.6	97.5	99.5	113.6	31.7	4490	1249	1.022
3199	98.8	784	98.2	96.9	100.3	112.8	31.6	4450	1252	1.013
3163	98.9	781	97.8	97.0	100.2	112.3	31.5	4480	1240	1.008
1838	100.9	755	108.7	96.6	99.1	112.3	42.0	2370	1316	1.125
1202	101.0	780	107.4	93.9	100.2	112.0	43.7	2410	1322	1.144
1201	101.0	770	106.8	94.3	99.9	111.0	43.7	2380	1315	1.133
1625	100.9	754	107.9	95.4	98.9	110.9	43.6	2350	1318	1.131
3245	98.7	780	96.2	97.3	99.9	110.3	31.4	4510	1236	0.989
1984	100.7	743	106.6	97.6	98.7	109.9	41.2	2400	1299	1.092
1632	100.5	751	106.0	96.3	99.2	109.5	42.3	2360	1304	1.101
1200	101.0	757	105.7	95.1	99.2	109.0	43.5	2370	1310	1.111

Figure 6-3-3. Maximum High Performance Summary

This engine passes test cell criteria.



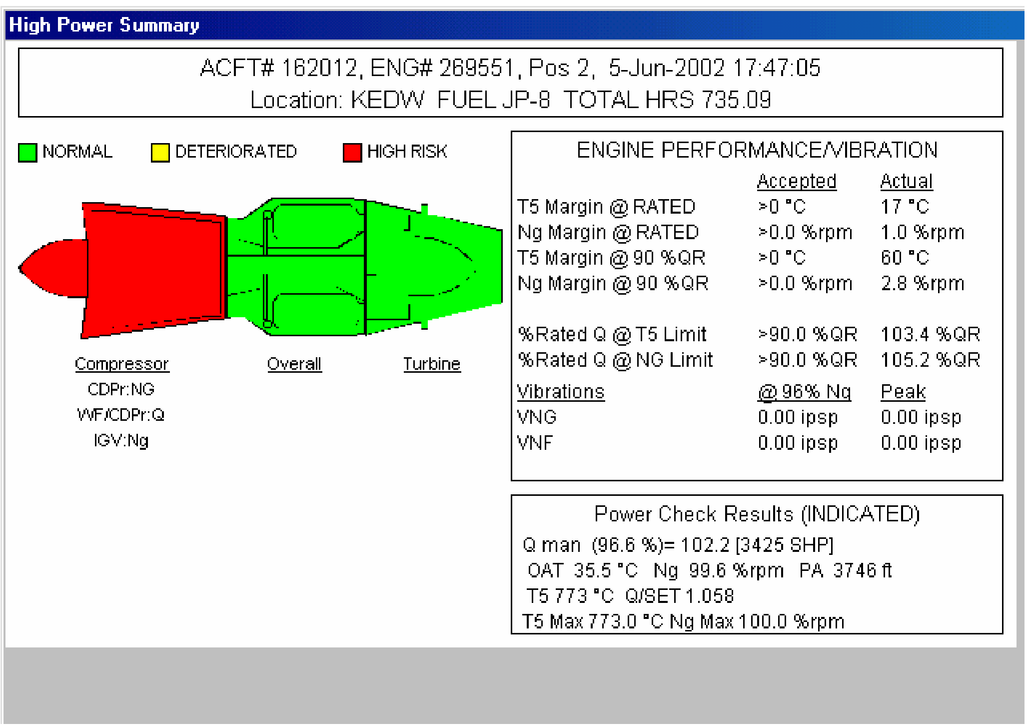


Figure 6-3-4. Simplified Presentation of High Power Summary, CH-53E

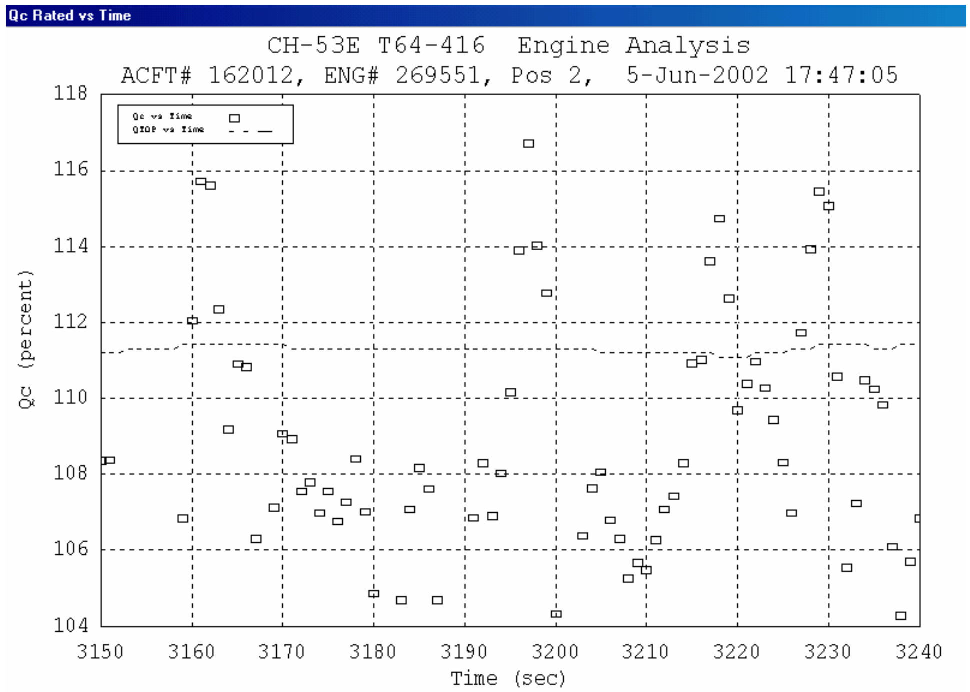


Figure 6-3-5. Torque vs. Time, CH-53E

Figure 6-3-5, Torque vs time during power check. Pilot chasing power setting. Engine never stabilized. Temperature lag causes invalid matching of data set.

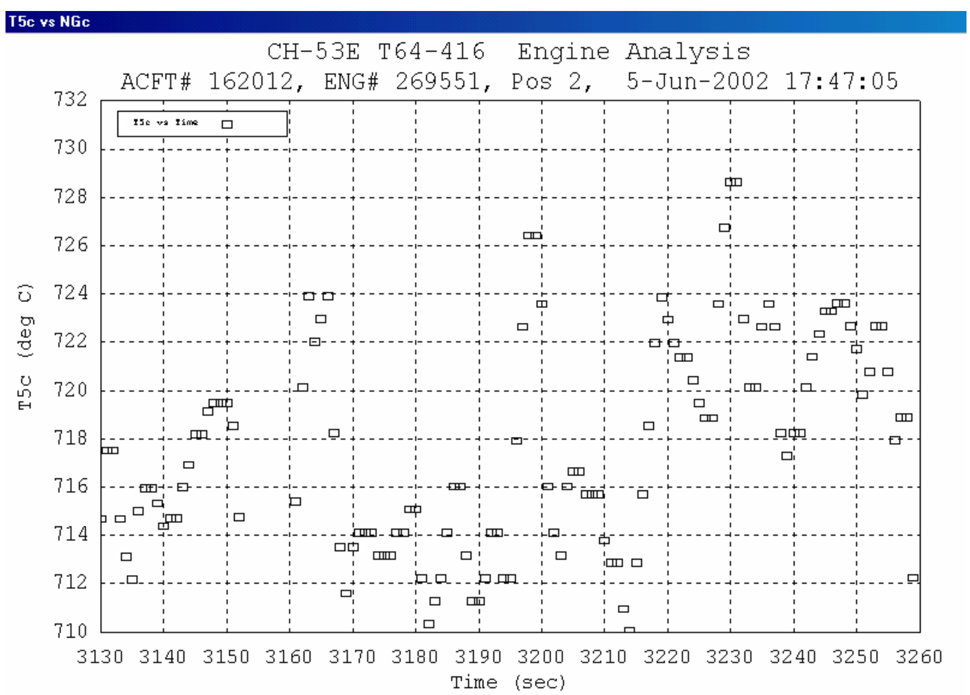


Figure 6-3-6. T5c vs. Time, CH-53E

Compare torque peaks with T5 peaks. Note 3 or more secs lag.

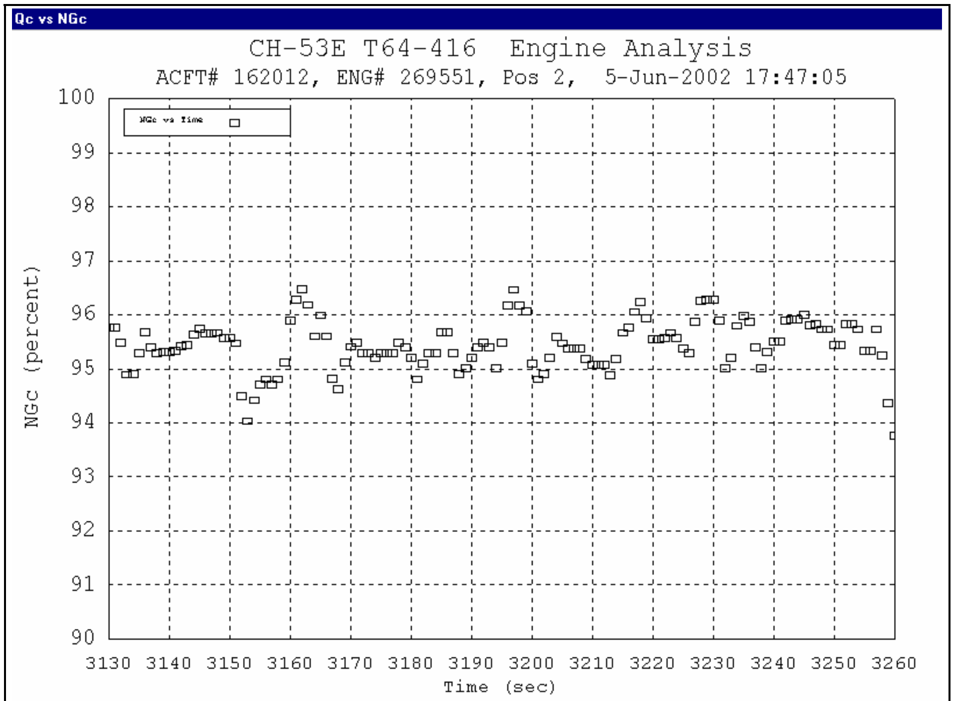


Figure 6-3-7. Ngc vs. Time, CH-53E

The replacement engine in Figure 6-3-7 operated with better stabilization. RPM within 1 % for 2 minutes. NOTE: RPM peaks before GT by several seconds.

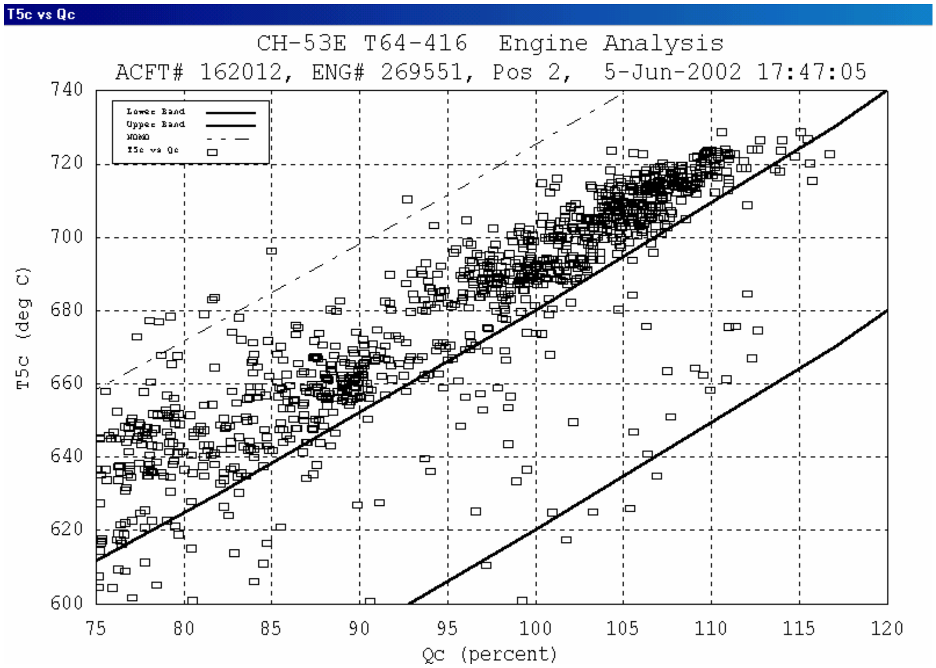


Figure 6-3-8. T5c vs. Torque

Note the lower T5 at the right end of the graph where thermal equilibrium is not met. The dashed line is the nomograph. Note the 25 °C margin for a 90% engine. The twenty top records show a 60 °C margin from lack of heat soak.

6-4 LESSONS LEARNED

The outcome of an engine test is to a great extent dependent on pilot technique. He must operate the test engine at a stable power level long enough to achieve thermal equilibrium. Changes in power level while recording data from one instrument at a time will pair up invalid readings introducing probable error in the engine evaluation. Slow reaction of the VGVs also adds variability in the engine operating line during power changes.

7-0 H-53 TEST RESULTS

7-1 NADEP CHERRY POINT H-53 TESTING

CH-53E #163073 and MH-53E #165204 were tested at NADEP Cherry Point during the month of August 2000. The CH-53E aircraft was a depot completion with three zero time engines installed. The zero time engines match the model very well. All three produced better than rated torque at limits. One high time engine was rated at 95.6% gas generator speed limit with the variable guide vanes out of the acceptable band on the plus (high) side. Another was a 97% power engine at temperature limit with VGVs out of the band on the low side.

Adjusting the VGVs to the correct setting would probably make these two engines capable of better than rated power. The following summary shows how the performances of these six engines compare.

Table 7-1-1. H-53E Cherry Point Test Results

SUMMARY DATA FROM NADEP CHERRY POINT H-53E JETCAL2000® ANALYZER TESTING

***************************	***************	******************	***************
DATE - AUGUST 17, 2000			
CH-53E AIRCRAFT # 163073	ENGINE # 1	ENGINE # 2	ENGINE # 3
ENGINE NUMBER	269771	269840	269840
HOURS	1.13	1.1	1.25
R TEMP MARG	22	20	15
R SPEED MARG	2.40%	3.20%	2.70%
90% R T MARG	66	63	59
90% R S MARG	4.10%	4.90%	4.40%
90% REJECT-TA@TEMP LIMIT	104.60%	104.10%	103.10%
90% REJECT-TA@SPEED LIMIT	111.80%	115.10%	113.10%
GAS GENERATOR VIBS	0.96	0.44	0.98
POWER TURBINE VIBS	0.22	0.67	1.O2
Ng SPEED:FUEL FLOW	-0.60%	-0.07	-1.3
CPR:Ng SPEED	-0.369	-0.628	-0.004
IGV POSITION/ ACCEPTABLE	N/U	N/U	N/U
TORQUE ERROR @ TOPPING	3.00%	5.00%	0%
T4.1 - DEGREES °C	1246	1225	1273
***************************	**************	******************	***************
DATE - AUGUST 23, 2000			
MH-53E AIRCRAFT # 162504	ENGINE # 1	ENGINE # 2	ENGINE # 3
ENGINE NUMBER	269788	816021	269888
HOURS	1966	1586	1598
R TEMP MARG	26	-13	22
R SPEED MARG	-0.80%	2.70%	2.80%
90% R T MARG	70	30	65
90% R S MARG	1.00%	4.50%	4.50%
90% REJECT-TA@TEMP LIMIT	105.30%	97%	104.5
90% REJECT-TA@SPEED LIMIT	95.60%	113.20%	113.60%
GAS GENERATOR VIBS	N/C	N/C	N/C
POWER TURBINE VIBS	N/C	"N/C	N/C
Ng SPEED:FUEL FLOW	3.00%	-1.30%	-1.20%
CPR:Ng SPEED	-1.819	-0.609	0.67
IGV POSITION/ ACCEPTABLE	5.1 / 2	-2.6/2.1	-1.5/2.1
TORQUE ERROR @ TOPPING	-5.00%	-2.00%	-2.00%
T4.1 - DEGREES °C	1094	1229	1252
***************************	**************	******************	***************

7-2 EDWARDS AFB CH-53E TESTING

H-53 testing was moved to HMH-769, Edwards AFB, CA, on May 15, 2002 to complete the COSSI T64 engine test. Data from three additional H-53E aircraft was required by NAVAIR 4.4.1 engineers to complete the JETCAL2000® Analyzer testing. Testing of the three additional CH-53E aircraft was completed on June 5, 2002.

The Reserve Marine Squadron was very cooperative during the testing. During the first week, only one aircraft was tested due to aircraft maintenance problems (start valves). The H337PA-603 performed and recorded data flawlessly.

REDD found two out of three engines in need of maintenance on the first aircraft. Technicians reset the VGVs and adjusted the torque system. These two engines are low time

with around 600 total hours. With correct adjustments they should operate at rated torque or better.

Maintenance technicians quickly grasped the correct interpretation of the REDD presentations. Using a projector, the REDD data was shown in the ready room to pilots and mechanics. Discussion indicated that the output information on engine condition and probable fix to faults identified would be very valuable to their maintenance operation.

Mr. Larry Switzer, NATEC Miramar, and Mr. Ced Daniel, Sikorsky Aircraft, were among those attending. Both helped install the equipment and use REDD. They both commented that the JETCAL2000® Analyzer offered a much needed capability. Mr. Daniels made sure that all three H-53E runs required to complete COSSI were accomplished. Mr. Therman Medlin represented Howell at Edwards AFB for the second week of testing.

Engine # 2, s/n 816139, on aircraft #162011 was replaced by engine s/n 269551 based on ground run data with the Engine Air Particle Separator (EAPS) doors closed. REDD requires flight conditions at the correct airspeed with the EAPS doors open to get a correct status on the engine's performance. Flight data at altitude showed engine s/n 816139 was able to produce 93% of rated power (90% is acceptable). It would run 30 °C above the GT limit if it were operated at rated power. The replacement engine ran 17 °C below the GT limit and produced 103.4% of rated power. VGV adjustment and compressor washes brought engines 1 and 3 on aircraft #162011 to better than 100 % rated power. The # 2 engine's VGV adjustments were causing it to run hotter than normal at all power settings.

Table 7-2-1. H-53 Edwards AFB Test Results

SUMMARY DATA EDWARDS AFB H-53 JETCAL2000® ANALYZER TESTING
NOTE: TA – TORQUE AVAILABLE

AIRCRAFT # 162011	ENGINE # 1	ENGINE 2	ENGINE # 3
ENGINE NUMBER	816132	816139	816129
HOURS	611	589	612
RATED TEMP MARG – DEGS °C	-10	23	-19
RATED SPEED MARG - %	0.6	-0.3	-1
90% R TEMP MARG – DEGS °C	33	67	25
90% R SPEED MARG - %	2.4	1.4	0.7
REJECT 90%-TA@TEMP LIMIT	97.7	104.8	95.7
REJECT 90%-TA@Ng LIMIT	103.3	98.2	94
GAS GENERATOR VIBS	N/C	N/C	N/C
POWER TURBINE VIBS	N/C	N/C	N/C
Ng SPEED:FUEL FLOW	1.2	1	1
CPR:Ng SPEED	- 1.275	-1.386	- 0.894
IGV POSITION/ ACCEPTABLE	5.3 / 2	3.9 / 1,9	2,5 / 1.9
TORQUE ERROR @ TOPPING	-3.0%	-2.0%	-14.0%
************************************	*****************	************	************

AIRCRAFT 162012	ENGINE # 1	ENGINE # 2	ENGINE # 3
ENGINE NUMBER	269753	269757	269295
HOURS	1755	2420	1813
RATED TEMP MARG – DEGS °C	0	-30	9
RATED SPEED MARG - %	2.6	1.2	0.2
90% R TEMP MARG – DEGS °C	44	14	53
90% R SPEED MARG - %	4.4	2.9	1.9
REJECT 90%-TA@TEMP LIMIT	100	93.1	102
REJECT 90%-TA@Ng LIMIT	113	106.1	101.2
GAS GENERATOR VIBS	0.29	0.58	0.71
POWER TURBINE VIBS	0.25	0.27	0.48
Ng SPEED:FUEL FLOW	-0.8	0.4	1.3
CPR:Ng SPEED	-0.028	-1.454	-0.794
IGV POSITION/ ACCEPTABLE	-0.4 / 2.0	5.1 / 2.0	4.9 / 1.8
TORQUE ERROR @ TOPPING	+2.0%	-4.0%	-4.0%
***********************************	*****************	************	************

AIRCRAFT # 165346	ENGINE # 1	ENGINE # 2	ENGINE # 3
ENGINE NUMBER	816124	816126	269002
HOURS	791.3	782	550
RATED TEMP MARG – DEGS °C	47	34	28
RATED SPEED MARG - %	0.4	1	2.4
90% R TEMP MARG – DEGS °C	91	78	72
90% R SPEED MARG -%	2.2	2.7	4.2
REJECT 90%-TA@TEMP LIMIT	109.6	106.9	105.7
REJECT 90%-TA@Ng LIMIT	102.3	104.9	112
GAS GENERATOR VIBS	0.4	0.33	1.14
POWER TURBINE VIBS	0.44	0.43	1.02
Ng SPEED:FUEL FLOW	1.3	1	- 1.5
CPR:Ng SPEED	- 0.877	-1.089	0.144
IGV POSITION/ ACCEPTABLE	OFF SCALE	0.3 / 2.0	OFF SCALE
TORQUE ERROR @ TOPPING	-3.0%	-2.0%	-2.0%

7-3 USAF H-53J/T64-100 TESTING

During June 2002, at the USAF T64 Engine Users Conference held at Hurlburt Field, Florida, the potential maintenance improvements offered by the H337PA-603 JETCAL2000® Analyzer were addressed. An action item was assigned to evaluate the test set and its Referred Engine Diagnostic Data (REDD) system. The test set and REDD system were demonstrated on the 58 MXS Test Cell facility (A T-24 trim trailer bought by the US Army) and the 551 SOS MH-53J aircraft application at Kirkland AFB, NM, July 15-19, 2002. The data from this test cell operation gives a good example of where the engine symptoms in the manuals do not match reality and do not lead to the correct repair action.

7-3.1 Test Cell Operation

Test Cell personnel stated, "The overall fit and function of the test set was outstanding and the REDD system was user friendly." The JETCAL2000® Analyzer test set installation kit is designed for installed engine testing. However, with a modified installation kit, it can be used in parallel with the Flexible Engine Diagnostics System (FEDS). The FEDS is a T-24 Trim Trailer with an Automated Engine Data Acquisition Test Set (AEDATS). The FEDS torque monitoring system output was not compatible with aircraft signal and therefore could not be connected to the JETCAL2000® Analyzer test set. This was known and Howell will develop this system if needed for test cell use. Even without a torque input, the H337PA-603 with REDD demonstrated its outstanding value on the test cell.

The test cell engine originally failed with low power. In Figure 7-3-1, Figure 7-3-2, and Figure 7-3-3 REDD shows the VGVs operating outside the acceptable band, the CDP for the Ng speed over a ratio below the expected performance, and gas temperature low for Ng speed. VGV rigging was checked and the engine retested. VGVs were still out of the band on the high side. The higher the VGV angle the lower the angle of attack on the rotating compressor blades. A lower angle of attack on the compressor blades results in more gas generator speed from less drag, but less pressure rise as seen in the CPR.

The fuel control was changed and the engine retested. REDD for this engine test was near the center of the expected performance bands. The CDP and GT for the Ng speed ran near the center of the expected operating bands and the engine was accepted with a positive power margin. This data illustrates the great impact that VGV adjustment has on engine performance. The original scribe marks on VGV rigging may not be at optimum position if environmental erosion has changed the airfoil shape. REDD presents the power check results in numerical format with torque at Ng and GT limits to a tenth of a percent. With REDD, the technician can see the effect of any change in VGV position on the engine's torque (SHP) at the GT or Ng speed limits to this tenth of a percent.

The following six graphs illustrate how the engine performed as received on the test cell with a probable faulty Compressor Inlet Temperature (CIT) sensor and with correct VGV operation. Note how the T5 and CDP went to the center of the expected performance band when the VGV went to center of its recommended setting band. The engine start times in the title blocks allow the reader to relate the CDP and T5 performance graphs with the correct VGV setting graphs.

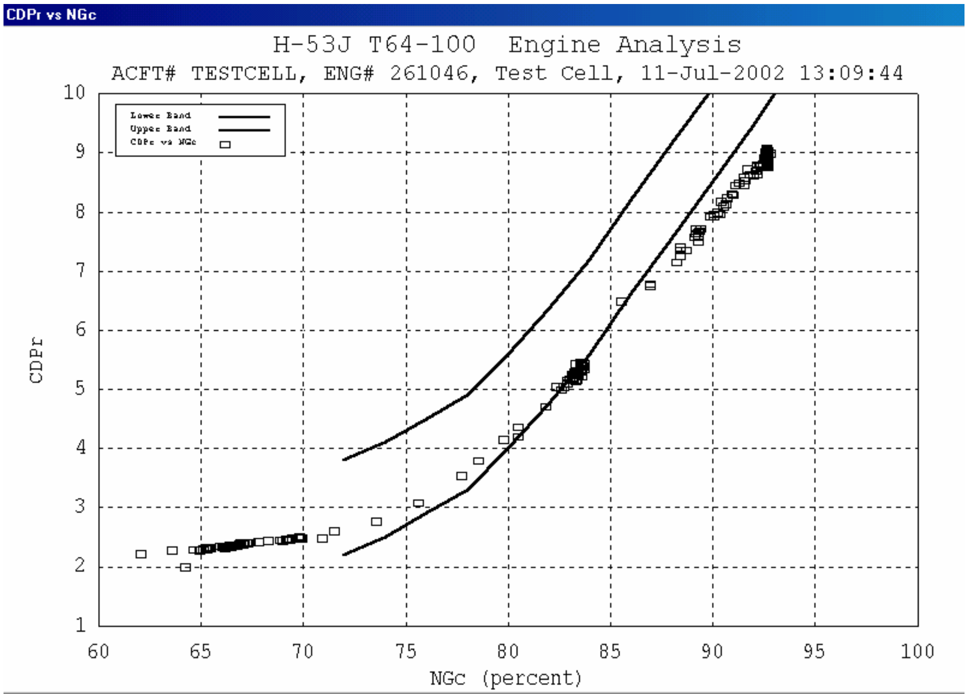


Figure 7-3-1. CDPr vs. Ngc, H-53J

Note the compressor discharge ratio dropping below the T64 expected performance band. The center of the band is ideal model performance.

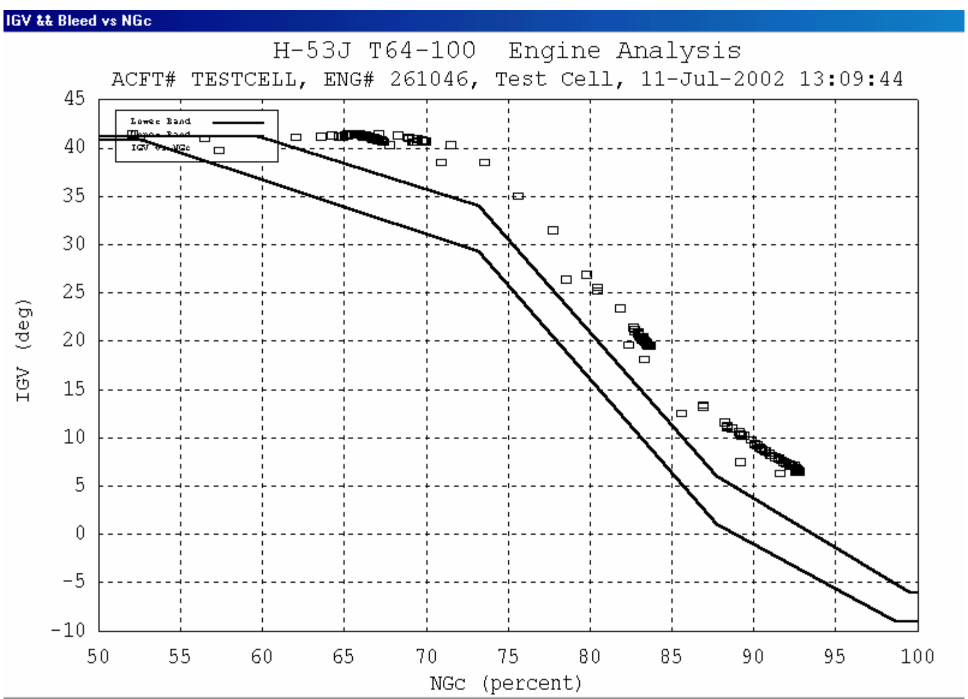


Figure 7-3-2. VGV vs. Ngc, H-53J

Note the VGV track well out of the desired band on the high side.

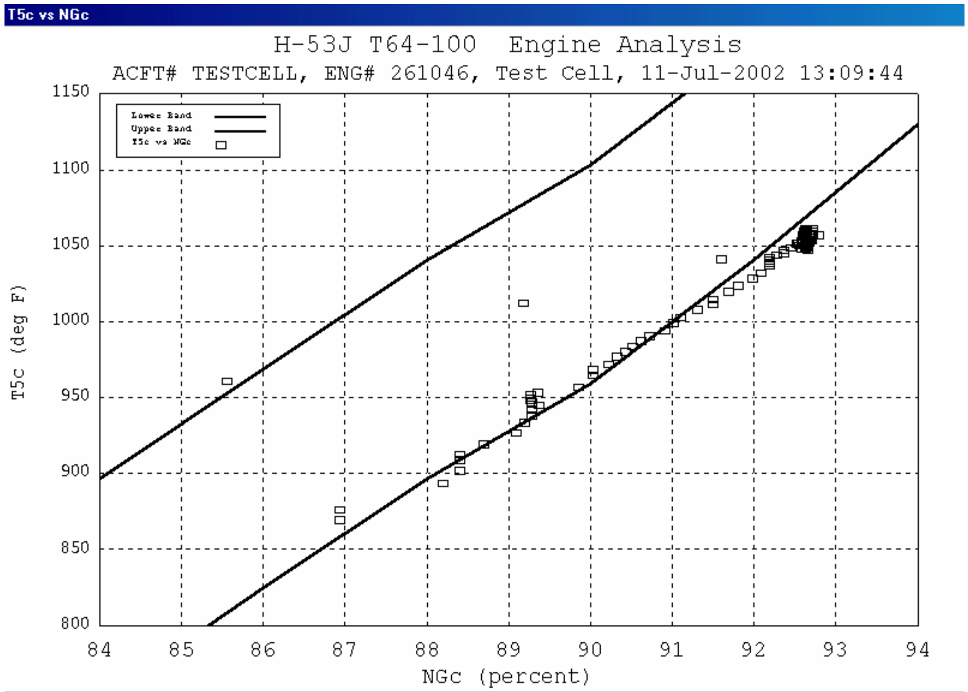


Figure 7-3-3. T5c vs. Ngc, H-53J

Note the low T5 (-80 °F) for the gas generator speed (Ng) = 92.7%.
NAVAIR 02B-105AJB-6-1, Troubleshooting, Table 15, gives engine symptoms for fuel control failure to schedule VGV as high T5 at Ng versus the low T5 observed.

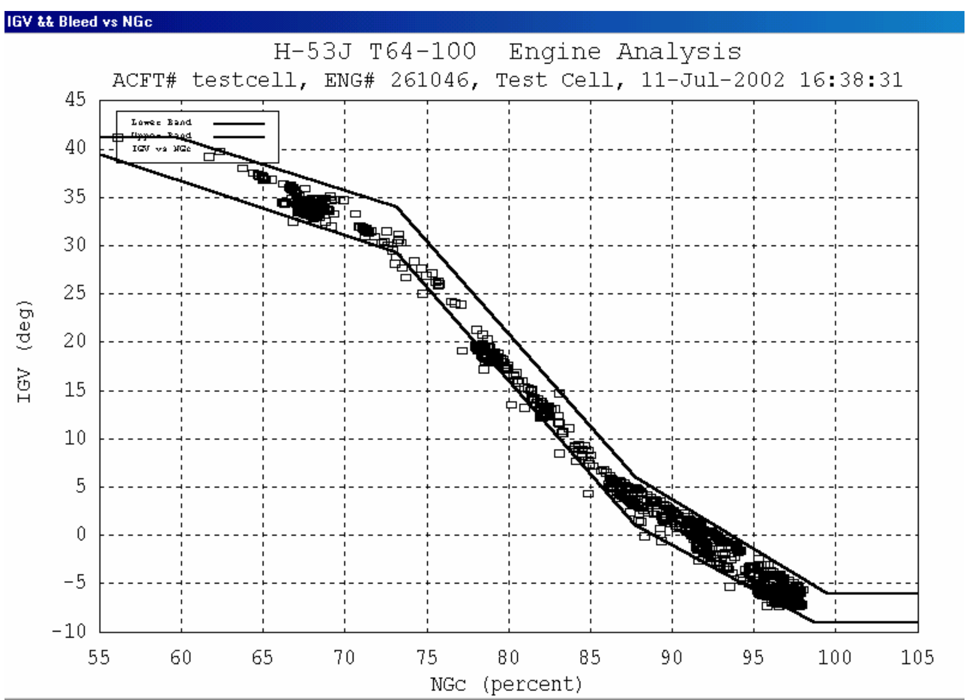


Figure 7-3-4. VGV vs. Ngc, H-53J

VGV track after fuel control change.

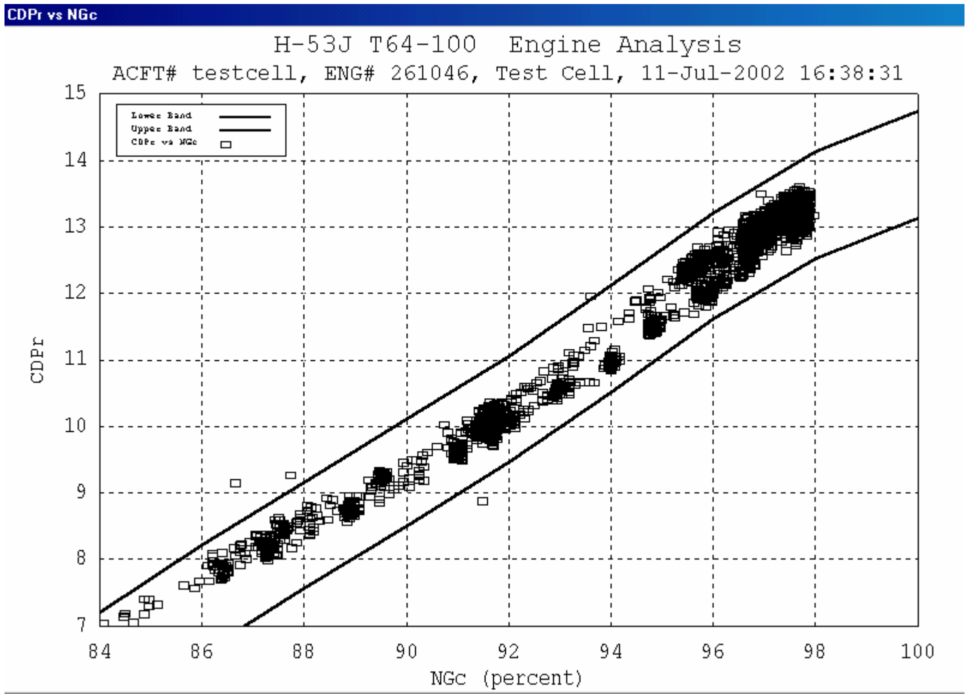


Figure 7-3-5. CDPr vs. Ngc, H-53J

Note the normal compressor performance.

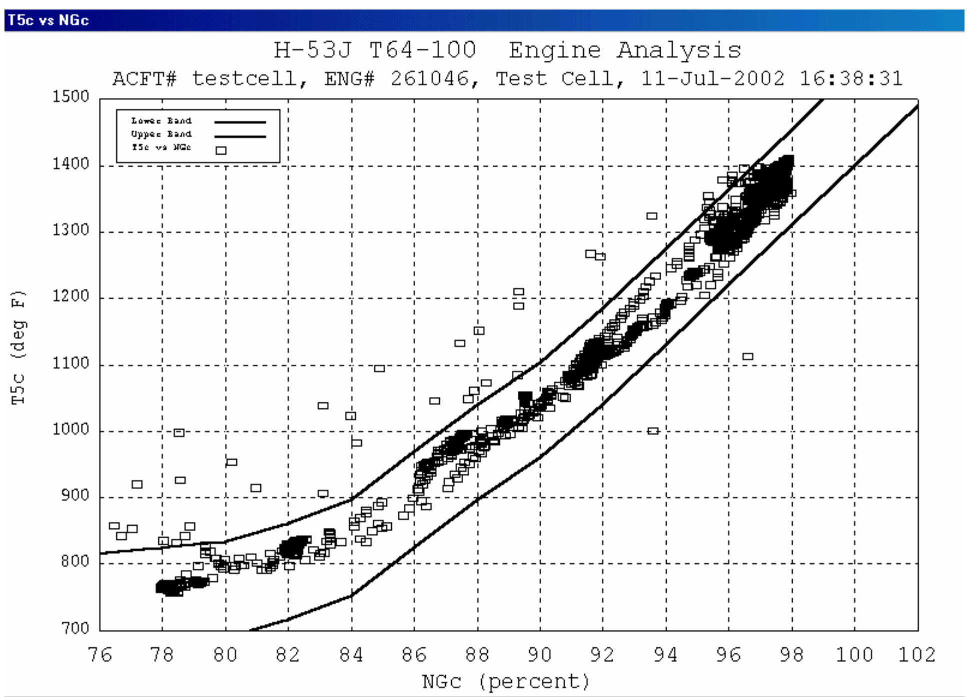


Figure 7-3-6. T5c vs. Ngc, H-53J

Note T5 running near the center of the band for model engine performance.

An installed test of this engine with the JETCAL2000® Analyzer prior to removal would have identified the faulty VGV track. A fuel control change would have avoided an engine removal and shop visit. The savings from keeping this engine in service with restored performance are $75,000–one half life extension. (See savings analysis).

Test cell management can certainly benefit from using the JETCAL2000® Analyzer as a portable tool that simultaneously verifies test cell calibration. The JETCAL2000® Analyzer readings, traceable to national standards, validate test cell parameter readings without use of a gold-plated engine. The test set can be used as a screening tool. If the JETCAL2000® Analyzer verifies the test cell instrumentation accuracy, then the next periodic evaluation with a gold-plated engine can be delayed. Test cells with channels that are found to be inaccurate can be scheduled for earlier attention. This could reduce the cost of checking test cell accuracy with a gold-plated engine, lower the man-hours required for the annual test cell calibration task, increase user confidence in test cell accuracy, and increase test cell availability.

7-4 Summary

Installed Engine Results

Overall fit and function of the H337PA-603 on the H-53J were excellent. Operation of the REDD system for flight line maintenance personnel was outstanding. Two small system problems were encountered and have subsequently been corrected by Howell. The H337PA-603A is now completely ready for use on the H-53J helicopter.

7-5 USAF H-53J/T64-100 Test Cell Experience

Engine s/n 261046 was removed for due to low power and sent for repair. The repair action was teardown with removal and replacement of all substandard parts. The engine was then sent to the test cell for after repair checks. The engine failed with low power. (VGVs were later found by REDD as not in acceptable band). VGV rigging checked and found to be OK. The fuel control was changed and the engine retested. It passed with a power margin. This example clearly shows the power of REDD as a quality control repair verification tool, as an installed test of this engine with the JETCAL2000® Analyzer prior to removal would have identified the faulty VGV track (VGVs out of acceptable band on the REDD graph). A fuel control change on the installed engine would have avoided removal and a shop visit. The savings from keeping this engine in service with restored performance are $75,000, as used in a COSSI savings analysis. From Navy sources, costs to the owning unit are $150,000 per engine removal.

NAVAIR 02B-105AJB-6-1, WP28 Troubleshooting, Table 15, gives engine symptoms for low power that begins with topping discrepancies as abnormally low Ng speed for T5 value or low torque at topping T5. This engine's T5 vs Ng graph shows the opposite - nearly 2% fast for the temperature. The symptom from the manual is opposite to that observed for this case of out-of-adjustment variable geometry schedule. Current technical manuals incorrectly point to a problem with the thermocouple harness when you have low GT for Ng speed. Engine s/n 261046 is an example of where the tech data gives criteria that do not match reality and lead to the wrong repair action.

A faulty fuel control is the ninth item in the trouble-shooting tree. Each of the faults that precede number nine would require the mechanic's time to check. The JETCAL2000®

Analyzer test run checks these items and records the results. Time to complete these tests is saved and that time savings exceeds the time needed to install and remove the test equipment.

7-6 JETCAL2000® Analyzer Functions as a Full Time Engine Monitor

One of the first two JETCAL2000® Analyzer prototypes is being used as a full time engine monitoring system on a CH-46E at HMX-1, MCAS Quantico. The aircraft is the test bed aircraft for the initial delivery T58-GE-16A engines under Engine Reliability Improvement Program (ERIP). The recorded data from the JETCAL2000® Analyzer has established performance base lines and is tracking performance during the testing program. The REDD information from the first engine tested shows rated torque with 16 °C GT margin and 0.2% gas generator speed margin. The engine capability limits are 105.0 % rated torque at GT limit and 100.2 % rated torque at the Ng limit.

The data was very valuable in understanding the severity of a torque split problem encountered in initial testing and validating its correction. To help with understanding the torque split problem, an additional cable was made to connect the collective and actuator position voltages from the Engine Condition Control System (ECCS) to the JETCAL2000® Analyzer. The voltages were measured and recorded for determination of their value each quarter of a second during operation. The accurate data was very helpful in understanding the situation.

7-7 Diagnostic Capabilities Demonstrated

The JETCAL2000® Analyzer, H337PA-603 provides portable installed engine test cell capability with ability to perform prognostic or diagnostic fault isolation analysis for turbine engines. The data analysis results have validated the test sets potential for immediate O&S cost savings under field use. These tests validate the test set's capabilities and benefits as described in the original COSSI proposal.

Experience and analysis of turbine engine failure modes has shown that real hardware failures that cause gas turbine speed slow down for torque and fuel flow are not all detected by current test cell criteria or in-flight performance check methods. No criteria in any manual or troubleshooting tree suggest the slow gas generator speed at power represents a developing internal hardware problem. Jim Pettigrew's paper "Effective Turbine Engine Diagnostics" presented at IEEE AUTOTESTCOM on August 23, 2001 describes these hidden failure modes that even a test cell run cannot detect. (The paper can be viewed on the Howell Instruments, Inc. web site, www.howellinst.com.).

Lack of evaluation criteria causes current turbine engine test methods to fail in the detection of serious hidden faults. The H337PA-603 JETCAL2000® Analyzer Data Reduction Program (DRP) includes criteria to flag these hidden faults.

Initial testing clearly demonstrated that the JETCAL2000® Analyzer's accurate data recording capability reduces the window of uncertainty and greatly enhances installed engine performance testing and data interpretation. Engines certified by current engine performance verification techniques were shown by the test set to have many hidden problems. These flaws include often inaccurate and imprecise aircraft instrumentation, errors in the manual recording and manipulation of data, VGVs operating outside the acceptable band, and no criteria for evaluation of some hidden failure modes, such as slow Ng speed at power and unusual fuel pressure at fuel flow, indicating fuel nozzle malfunction.

The test set provides a time tagged quarter second by quarter second operating history of installed engines. A single manually recorded data set at one, three, or four test points is all that has previously been available. This additional information has demonstrated that some past assumptions about performance degradation are incorrect. As an engine deteriorates, the various performance indicators do not necessarily change in a manner that is intuitively obvious or written in the tech manuals. The complexity of installed engine performance and the shortcomings of current instrumentation and manual data manipulation make JETCAL2000® Analyzer data a prerequisite to verifying installed engine performance potential and diagnosing hidden discrepancies.

7-8 Field Torque System Error Identification

Field maintenance personnel check torque reading accuracy by setting 100% engine gas generator speed, then by comparing the torque readings. They can do this by singly advancing each engine to 100 %Ng speed, then by noting its torque reading. With three engines, the two closest readings are averaged, then the third engine is adjusted to the first two's average. The actual Ng readings recorded during the first setting of each engine at 100% were #1, 99.5 %, #2, 100.0%, and #3, 99.0% per the calibrated JETCAL2000® Analyzer readout. Variance in setting the Ng RPM indicators influence the torque values to be matched. Another variable introducing error in this method is the influence of each engine's internal nozzle areas and VGV settings on the power it can produce at a given engine speed. Therefore, the above procedure is flawed in more than one way. Instead of increasing torque system accuracy, its use is likely to create unwanted error in the indicating torque system. Engines operating at the same torque may well indicate different RPM, GT, or fuel flow. Should torque match one of the parameters it probably will NOT match the other two. Using the matching indicated torque to indicated RPM method on a two engine aircraft caused maintenance actions to continue on the wrong engine for four months until REDD data showed what torque an engine should be expected to produce. The labor and parts wasted on the wrong engine, while not quantified, had to have a significant impact on the unit's budget.

7-9 Enhanced Torque Measurement Using Model Based Analysis

The torque indicating system on any turbo shaft engine is potentially plagued with multiple degrading factors that can affect the cockpit torque indication. Temperature and torque stiction are known to cause unacceptable errors in the torque indication system. Unfortunately, torque is a critical parameter used by the pilot in evaluation of engine condition. Lack of accuracy in the torque indicating system can invalidate decisions by the flight crew.

Howell Instruments has recognized the problem with lack of accuracy in the indicated torque reading and has created a method to cross-correlate the indicated torque with a model-based expected torque derived from the other engine parameters. The Howell patented REDD program examines the relationship between parameters with model-based upper and lower limits. We achieve a high degree of confidence in determining the expected torque with REDD by accurately measuring Ng, TGT, fuel flow, and CDP. Quite simply, the more additional parameters examined, the higher the confidence factor in the expected torque analysis results. REDD has been developed, refined and proven with hundreds of engine runs over the last two decades. The attached graphs show a representative correspondence of Indicated Torque vs Expected Torque model.

If the expected torque is consistent with the indicated torque, then the indicated torque is correct. If the torque is out of line with all the other parameters, REDD synthesizes a expected torque value. With REDD the ability to determine engine performance (expected torque) that the engine is able to produce under current environmental conditions is a leap forward in verifying cockpit torque system accuracy. Knowing the accuracy of the cockpit torque instrument has a direct impact on the evaluation of engine suitability for further service.

The H337PA-603 accurately reads the aircraft instrument sources and provides an independent torque value that the engine is producing using thermodynamic relationships between the engine variables. The analysis program produces REDD graphs that show indicated torque plotted against engine model torque equivalent based on indicated gas temperature, gas generator speed, fuel flow, and compressor pressure ratio in percent. One presentation shows the indicated torque reading on the Y- axis with the Model thermodynamic torque on the X- axis. Zero error exists when the indicated torque equals the reference line. If error is present, the indicated torque line deviates from the reference line. A second presentation shows the difference between model and indicated torques as a percent error plotted against indicated torque. Graphs from two data sets follow. One set shows minimal torque error. The second shows an engine with a 15% indicated torque error. This engine would be failed and removed from the aircraft due to the error in this indicating system but would check OK on a pre-teardown test cell run. The low values at 70% to 80% on both data sets are flight data recorded with the EAPS doors closed (causing erroneous REDD information).

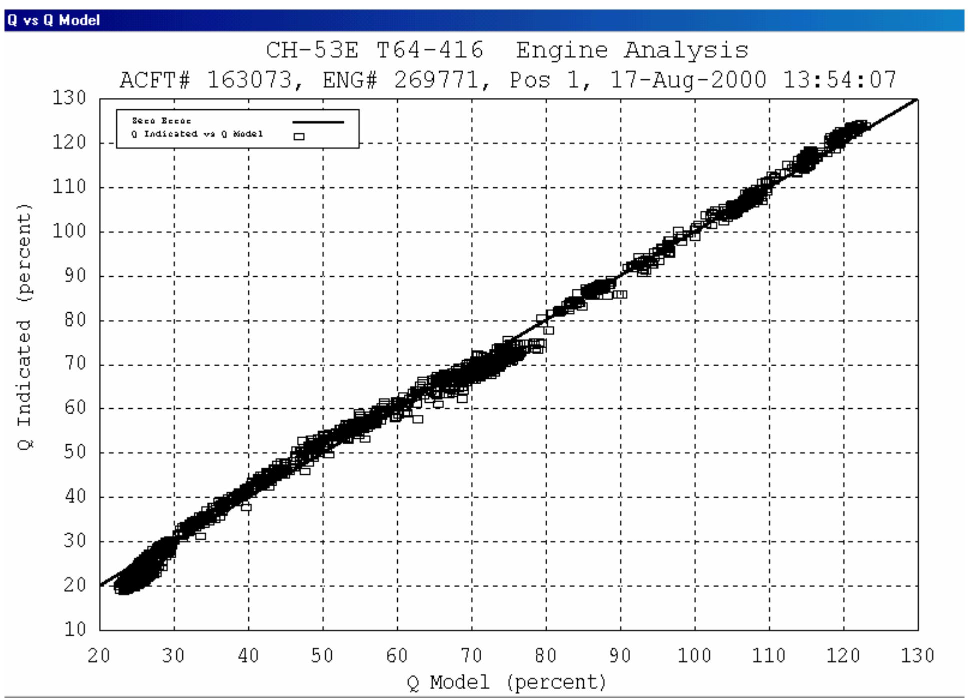


Figure 7-9-1. Q Indicated vs. Q Model, CH-53

Example of an engine where Indicated Torque follows the Torque Model.

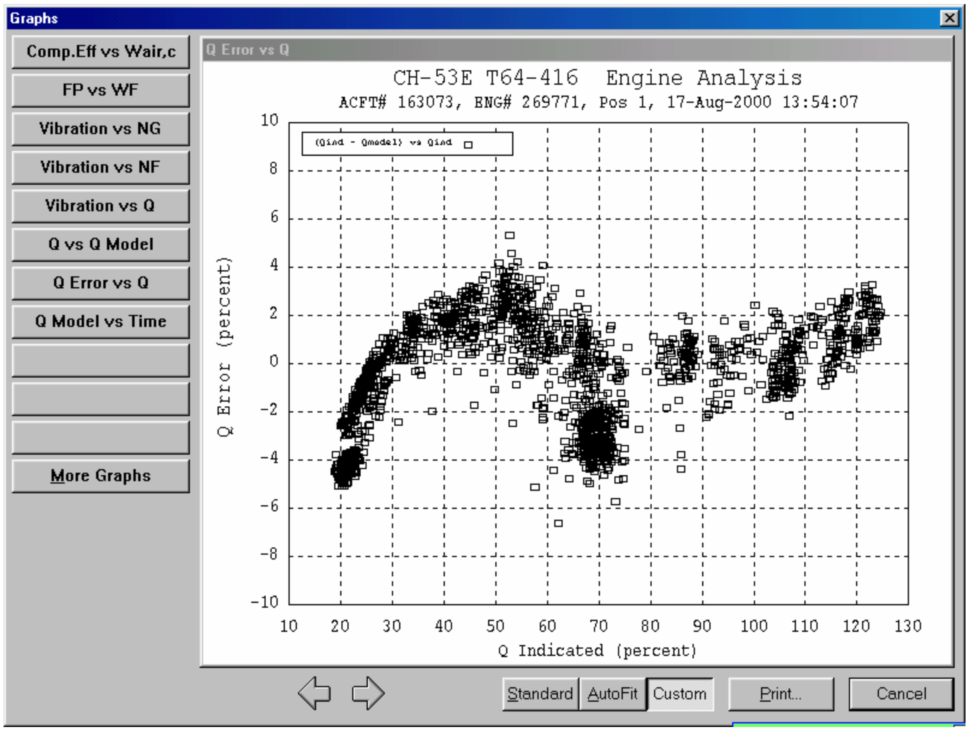


Figure 7-9-2. Q Error vs. Q Indicated, CH-53

Example of torque error where indicated torque does follow the torque model.

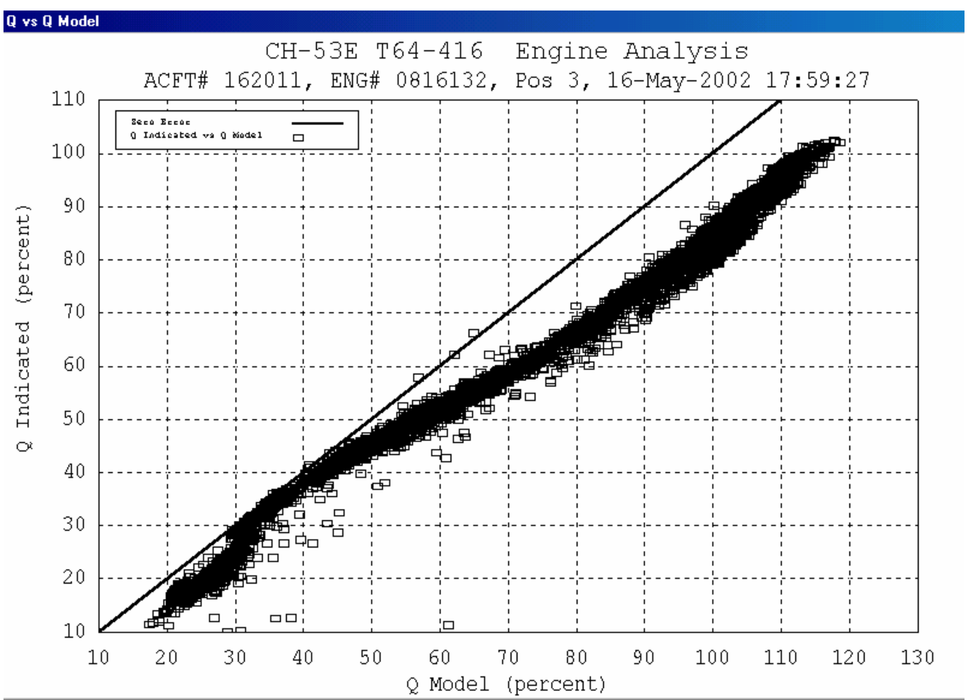


Figure 7-9-3. Q Indicated vs. Q Model at High Power, CH-53

Example of how indicated torque deviates from the model at higher power.

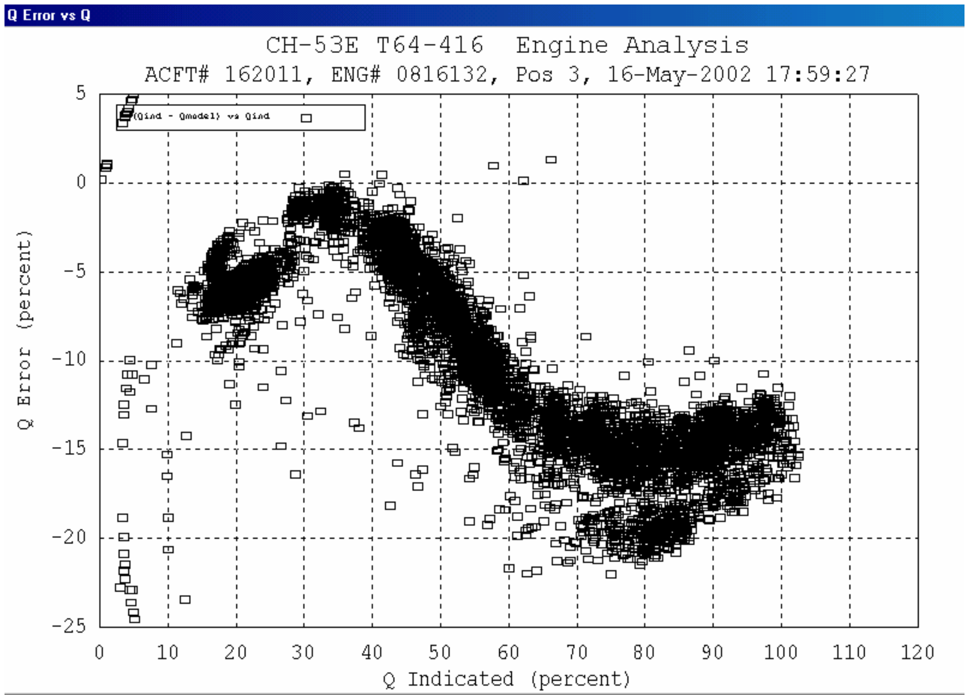


Figure 7-9-4. Q Error vs. Q Indicated, CH-53

Example of torque error where indicated torque does not follows the torque model.

7-10 Army Savings Analysis

Army Aviation Systems Command Data Analysis and Control Division–Cost Estimate Control and Data Center performed a Portable Turbine Engine Analyzer (PTEA) Savings Analysis, Control No. 90-0050, at validation level II. That project's objective was to decrease operating and support cost of U S Army helicopter engines. The project found a savings to investment (S/I) ratio of 1.57 and a payback 5 years after fielding. This analysis recommended purchasing and fielding the Portable Test Engine Analyzers (PTEA). It stated the following:

1. The benefit analysis clearly shows the PTEA is superior to Turbine Engine Analysis Check (TEAC).
2. A PTEA can reduce aborted missions by 8%.
3. The 5-year payback and 1.57 savings-to-investment ratio justify acquiring PTEA on the basis of cost savings.
4. There are other important but difficult to quantify savings, such as:

- Less secondary engine damage due to early detection of problems
- Potential for changing periodic to on-condition maintenance
- Increasing aircraft availability and mission readiness by decreasing the number of mission aborts and aircraft mishaps.
- Reducing the cost of turbine engine repairs, stockpiling parts, and shipping
- Limiting the amounts of test equipment required in operational aviation units

- Augmenting the accuracy of engine performance data and establishing a life cycle historical data base on each engine that unit and higher maintenance activities can access

5. Review of the JETCAL2000® Analyzer test set capabilities shows that it provides its user with the following maintenance enhancements:

- Standardized installed engine test methods among using field units, with a new capability to validate the results of repair on installed engines.
- Enhanced fault isolation by providing highly accurate test data and eliminating errors caused by human factors.
- An easy and accurate method to test VGV and Bleed Band operating schedules in an operating environment.
- A certified standard the field with against which to check installed cockpit engine instruments in actual operation.
- An assessment of engine condition from a ground run equivalent to that obtained on a test flight. This solves a current operational problem that allows sign-off and continued operation of engines with unverified performance when cold ambient condition prevents reaching topping conditions. Potential to identify problems on ground run before flight may allow normal repair before maintenance flight test with appreciable savings.
- Added sensors to provide ways to detect previously undetectable problems such as fuel nozzle back pressure - thermocouple harness breakdown at high power settings, loss of compressor stall margin and compressor shroud rub at high power.
- An enabled diagnostic center to centralize expert engine analysis and validate field troubleshooting either as a support service or as an in-house responsibility. Users can transmit digital files of engine test data from any location with a telephone line or email.
- A simultaneous record of flight conditions and data from vibration tracking filters that can differentiate between expected high vibration readings and failure warnings.
- The capability of recording data of all monitored parameters at one-quarter second intervals for improved isolation of unknown transient problems.
- Enhanced flight safety by providing an improved and standardized database capable of directing the on-condition maintenance concept with FLY, DETERIORATED, or HIGH RISK information.

8-0 H-46E TEST RESULTS

8-1 NADEP Testing Startup Events

Necessary flight releases for the test and evaluation of the JETCAL2000® Analyzer were obtained. A form, fit and function was completed during January 19-23, 1999. NADEP Cherry Point Flight Test provided a H-46E aircraft and crew for verification of the installation kit and a ground turn using aircraft # 153981 on January 20, 1999.

With the exception of fuel flow, fuel pressure and compressor discharge pressure not being connected due to incorrect threading of fittings, the test set recorded data and produced Referred Engine Diagnostic Data (REDD) as expected on the ground turn.

Engine #1 showed a 5 °C Temp margin, a plus 1.9% Ng margin (plus is good; minus is unsatisfactory) and 101.1% rated power (95% is acceptable).

Since the amount of power that can be used on a ground turn is limited, proper performance of the power check is not possible and will be reported by the JETCAL2000® Analyzer. A message on the component deterioration summary provides information that the power checks on the ground have not been properly performed.

Engine #2 showed a 5 °C temperature margin, a –1.2% Ng margin, a capability of 94.5 % of rated power based on gas generator speed limit, and low power at gas generator speed limit. REDD directed the technician to check and optimize VGV adjustments.

Major Dahl, H-46 test pilot, reported that after flying five test flights, he reached the same conclusion that the JETCAL2000® Analyzer had reported from the ground run. The potential savings associated with beginning maintenance action based on the JETCAL2000® Analyzer ground run versus the man-hours and five test flights at $6,100 per hour is $30,500.

NOTE: These potential savings are not included in Life Cycle Cost Savings studies contained herein.

Ground testing of the JETCAL2000® Analyzer on the H-46E, #155303 with all inputs operating was completed April 8, 1999. Both engines on this aircraft showed acceptable performance.

Form, fit and function of the JETCAL2000® Analyzer on the H-46D airframe was satisfactorily completed June 10-11, 1999, without using an airframe modification. Both engines showed normal operation. The test aircraft had hard fluid lines installed across the VGV pickup point. These lines are not shown in the T58-402 tech manuals. H-46D installation kit hardware has been changed to allow the VGV sensor to be installed on a -402 engine.

8-2 Results From H-46E Testing

The first flight of a JETCAL2000® Analyzer on a H-46E, #154040 occurred on March 28, 2000. The system worked as expected showing that both engines met minimum requirements. REDD showed one engine with a decreasing temperature margin after the VGVs reached full open. Adjustment of the full open position could recover 15 degrees or more of the engine's temperature margin. A 25 °C Gas Turbine Inlet Temperature (T4.1) increase cuts hot section life by approximately 50%. The aircrew also found both engines to be acceptable.

Two H-46 flights were successfully completed during August and September 2000. The H337PA-603 test equipment and the diagnostic analysis disclosed abnormalities and hidden faults in five out of eight engines that had been signed off as ready for issue to the fleet using nomograph procedures. Correction of these faults would increase power output and increase useful engine life.

On September 11, 2000, the third H-46E aircraft #156418, a depot inbound, was flown using the JETCAL2000® Analyzer. The pilots found both engines to be acceptable by the nomograph method. REDD analysis found Engine 1, s/n 216621, acceptable by the nomograph method at 99.6% of rated power.

REDD analysis showed an error in the installation of the test kit. Technicians had swapped the electrical connection for compressor discharge pressure and fuel pressure transducers. Engine #1's compressor ratio at power was apparently low by more than three ratios, 40% low at rated power. The fuel pressure to fuel flow ratio was high at lower power and had a downward deflection at higher powers. The curve shapes graphed by REDD are consistent

with our expectations when the Compressor Discharge Pressure (CDP) electrical connection is on the Fuel Pressure (FP) transducer and vice versa. The downward slope on fuel pressure is the same shape as a CDP curve. The installation error made both CDP and FP unusable in the analysis.

The VGV position is above the band on the high end, which explains the fast Ng speed that limits engine output to 98.9% at Ng speed limit. The T58-16 nomograph passes a 95% rated power engine. This engine was temperature limited at 98.2% rated power. Clearly, this engine should be sent to the test cell. The VGV should be adjusted to bring the engine up to standard performance rather than being re-installed in its current marginal condition.

REDD analysis showed Engine 2, s/n 216088, was speed limited at 92.4% rated power. The VGV stopped just above the full open band. The high side of the band unloads the compressor by lowering the angle of attack on the blades and lowering the achieved pressure ratio by 0.53 ratios below expected. A VGV adjustment to mid-band would slow the Ng speed at power and make this engine achieve rated power. Although this is an unsatisfactory engine capable of less than 95% rated power, it will not be identified by the nomograph method of engine testing. This would be another engine with a 'serviceable' tag that really should be adjusted or repaired before being returned to service. REDD analysis showed 'serviceable' engines actually in need of work.

Table 8-2-1. H-46E Cherry Point Test Results

NADEP CHERRY POINT H-46E JETCAL2000® ANALYZER TESTING			05/06/02
****************	*************************	**************	************
GROUND RUN	ACFT# 153981	ENGINE #1	ENGINE # 2
JAN 20,1999	RT MARG DEGs °C	-2	-3
	RS MARG - %	2.0	-1.1
	95%RT MARG DEGS °C	14	13
	95%RS MARG - %	3.2	0.1
REJECT @ 95%	TORQUE AVAIL @TL	99.5	99.0
REJECT @ 95%	TORQUE AVAIL @SL	107.6	95.4
	GAS GEN VIBS	0.0	0.0
	PWR TURB VIBS	0.0	0.0
*************************	*************************	**************	************
GROUND RUN	ACFT# 155303	ENGINE #1	ENGINE # 2
APR 08, 1999	RT MARG DEGS °C	0	8
	RS MARG - %	1.5	0.9
	95%RT MARG DEGS °C	16	24
	95%RS MARG - %	2.7	2.0
REJECT @ 95%	TORQUE AVAIL @TL	100.0	102.5
REJECT @ 95%	TORQUE AVAIL @SL	106.0	103.4
	GAS GEN VIBS	0.4	1.0
	PWR TURB VIBS	1.0	0.9
*************************	*************************	*************	************
1ST FLIGHT	ACFT# 154040	ENGINE #1	ENGINE # 2
	RT MARG DEGS °C	3	-8
	RS MARG - %	3.8	1.2
	95%RT MARG DEGS °C	18	7
	95%RS MARG - %	4.9	2.3
REJECT @ 95%	TORQUE AVAIL @TL	100.8	97.3
REJECT @ 95%	TORQUE AVAIL @SL	112.9	104.6
	GAS GEN VIBS	0.0	0.6
	PWR TURB VIBS	0.5	0.6
*************************	*************************	*************	************
2nd FLIGHT	ACFT# 156418	ENGINE #2	ENGINE # 3
	RT MARG DEGS °C	-5	7
	RS MARG - %	-0.3	-1.7
	95%RT MARG DEGS °C	11	22
	95%RS MARG - %	0.9	0.5
REJECT @ 95%	TORQUE AVAIL @TL	98.4	102.1
REJECT @ 95%	TORQUE AVAIL @SL	98.9	92.5
	GAS GEN VIBS	0.4	0.6
	PWR TURB VIBS	0.9	0.8
*************************	**********************	***********	**********

8-3 Funding Shortfall—Testing Stopped

NAVAIR COSSI Program Manager, Mr. Charles A. Borsch, had indicated by telecom that additional funds could possibly be available early in the first quarter of 2001; however, they did not become available. Howell Instruments, Inc. attempted to have PMA 260 take over sponsorship of this project and fund completion of the field testing. Howell briefed PMA 260 personnel at Lakehurst NAS, February 15, 2001, on the COSSI 845 Agreement OT&E testing

of the instrumentation package and diagnostic software. PMA 260 acknowledged that the US Navy needed a turbine engine diagnostic capability and agreed to look for funds.

On April 11-12, 2001, Howell briefed PMA 261 at Patuxent River NAS on results from the one month of testing of the H337PA-603 on the H-53E aircraft. The need for additional funds to complete the Stage I OT&E at MCAS Cherry Point was discussed. A strong desire to complete the test was expressed by PMA 261 attendees. The propulsion engineer, Mr. Jon Pok, took the position that a General Electric Data Reduction Program (GEDRP) being evaluated on a T64 depot test cell at Cherry Point NADEP would likely negate the requirement for a portable on-board engine testing and diagnostic capability at the operational level. In this regard, it should be noted that one of the many benefits of on-board testing is the prevention of removing good engines from the aircraft to the test cell.

NAVAIR 4.4.1**,** H-46/T58 Propulsion**,** Mr. Greg Kilchenstein, coordinated an effort to move the Stage I OT&E test to HMX-1 prior to 9-11-2001. The subsequent tempo of operations at HMX-1 forced this plan to be placed on hold until March 26, 2002.

8-4 Test Schedule And Duration Addendum

PMA 226 AND 261 reviewed the results of the NADEP testing and recommended completion of the 845 agreements Stage I testing at HMX-1. Analysis of the H337PA-603 data showed that its ability to identify faults not identified by the nomograph method had been demonstrated.

8-5 NAS Patuxent River EMI Test

A New River MCAS H-46E aircraft, # 154851 was flown to the Navy Electro Magnetic Interference (EMI) test facility to evaluate influence of power radiation on a component of the electronic fuel control system. The EMI test occurred January 28-31, 2002. The H337PA-603, JETCAL2000® Analyzer was installed and included in the EMI test. No test set problem was noted in any of the test frequencies or powers. The H-46E aircraft was EMI certified for carrier operations with the H337PA-603 installed.

8-6 Quantico MCAS H-46E Testing

H-46E testing was moved to Quantico MCAS on March 26, 2002 to complete the H-46 COSSI test. NAVAIR 4.4.1 engineers required data from three additional H-46E aircraft to complete the JETCAL2000® Analyzer testing. Testing of the three aircraft was completed on March 28, 2002.

Table 8-6-1. H-46E Quantico Test Results

SUMMARY OF QUANTICO H-46E JETCAL2000® ANALYZER TEST

	H-46E ACFT# 157680	ENGINE #1	ENGINE# 2
	RT MARG DEGS °C	-4	-19
	RS MARG - %	-0.0	-0.6
	95%RT MARG DEGS °C	8	-3
	95%RS MARG - %	1.2	0.6
REJECT @ 95%	TORQUE AVAIL @TL	97.5	93.9
REJECT @ 95%	TORQUE AVAIL @SL	100.1	97.8
	GAS GEN VIBS	0.2	0.5
	PWR TURB VIBS	2.3	2.0
***************	*************************************	***********	***********
	H-46E ACFT# 157682	ENGINE #1	ENGINE # 2
	RT MARG DEGS °C	4	-33
	RS MARG - %	1.5	-0.3
	95%RT MARG DEGS °C	20	-17
	95%RS MARG - %	2.7	0.9
REJECT @ 95%	TORQUE AVAIL @TL	101.4	89.5
REJECT @ 95%	TORQUE AVAIL @SL	106.1	98.9
	GAS GEN VIBS	0.4	1.0
	PWR TURB VIBS	1.0	0.9
**************	**********************************	************	************
	H-46E ACFT# 157692	ENGINE #1	ENGINE # 2
	RT MARG DEGS °C	-9	-31
	RS MARG - %	0.8	-1.5
	95%RT MARG DEGS °C	7	-16
	95%RS MARG - %	2.0	-0.4
REJECT @ 95%	TORQUE AVAIL @TL	97.0	90.1
REJECT @ 95%	TORQUE AVAIL @SL	103.3	93.2
	GAS GEN VIBS	0.4	0.7
	PWR TURB VIBS	0.5	0.9
TL–TEMP Limit	-SL-Speed Limit	-	-
***************	*************************************	************	***********

9-0 FIELD EXPERIENCE FROM REDD USE

The President of Bladeaire, Inc. a maintenance contractor for Fort Bliss, Texas, learned of Referred Engine Diagnostic Data (REDD) capability and proposed use of the portable test capability in his contract bid. He proposed use of the test set prior to each aircraft phase inspection. The Army unit operated AH-1 and UH-1 aircraft using T53 engines. Prior to use of REDD, the AH-1S aircraft unit required 23 engines per year, averaged a compressor stall per month over the preceding three years, and had not been able to meet their annual flying hour allocation. The contractor obtained permission to adjust the engines' variable guide vanes in the field for optimum GT margin as measured by REDD. After performing pre-phase tests for a year and adjusting the VGVs for optimum performance, he only needed 13 engines, had no compressor stalls, and the unit met its flying hour allocation. A new engine from the manufacturer was identified by the test set as having a vibration problem. Teardown found 3 lbs of metal shavings inside the power turbine shaft. All test cell operations had

failed to detect the problem. An operating procedure was written requiring a REDD evaluation on all engines prior to acceptance or release for flight.

Using the two Measures Of Merit (MOM) testing–GT and Ng speed at rated torque–a T700 engine was sent to the repair facility for a new gas generator turbine. After repair, the engine failed the two power checks. The test set was installed and showed the compressor performance was three pressure ratios low. The real problem could have been identified with an installed test before removal and replacement of a $300,000 gas generator turbine that failed to fix the engine.

REDD diagnostic testing on CH-47C/T55-712 engines showed *compressor stalls* during start were the cause of slow starts. Before using REDD, mechanics changed five fuel controls at $500,000 each in an attempt to fix the slow start problem. Investigation revealed no problems in the replaced fuel controls. On teardown inspection of the engine, the last three compressor stages were very dirty. Technical manual procedures were allowing compressor washes with the bleed band open, allowing wash water to escape before effectively washing the last three stages.

REDD data has identified compressor shroud rub at high power conditions. However, considering the standard two Measures of Merit criteria only this engine was released to service. An analysis of recorded REDD data showed the abnormal operation that indicated the shroud rub problem. The aircraft was recalled, rechecked, and the rotor rub confirmed by the additional test data. After removal, disassembly of the engine allowed visual confirmation of the rubbing condition.

REDD has shown a failure mode of the gas generator turbine to be slow RPM at rated power. Most operators assume that as the compressor loses efficiency, the gas producer (GP or N1) "speeds up" to make up the loss in airflow. Data shows that degraded engines actually make rated power at slower gas producer speed than when they are in new condition. Current rejection criterion does not look for slower Ng operation. REDD does show speed limited as well as slow Ng speed engines.

REDD identifies gas temperature system problems that cannot be found at ambient temperatures. Gas temperature sensing harness exposure to the high hot end temperatures in a running engine can cause insulation break down and shorts to ground that are not present during normal low temperature ground testing. Comparison of indicated temperature to expected temperature at gas generator speed from the engine performance model would show low temperature indications that identify a malfunctioning gas temperature harness.

Discovery of hidden internal deterioration allows repair before secondary damage becomes excessive. Testing with REDD before phase inspections can identify hidden problems that can be corrected during scheduled down time. Repair of deterioration when it is beginning will reduce secondary damage while improving operational reliability, reducing in-flight problems and increasing flight safety. Aircraft with engines operating without hidden defects will stay in the aircraft longer, have increased combat capability and operate at a lower life cycle cost.

10-0 CONCLUSIONS

Installed testing with test cell equivalent instrumentation offers an improved diagnostic capability that is essential for accurate assessment of engine condition. Maintenance can fix the flaws, once they are known. Installed test cell instrumentation offers the flight line technician the basis to diagnose and repair engine malfunction. When faced with HIGH RISK, REDD values give him the data he can discuss with the engine analyst group. The expert analyst in the diagnostic center reviews the latest data from the specific engine, and communicates the best action to the flight line mechanic. It is a teamwork approach that will provide a new and improved dimension to maintenance and maintenance management.

From a flight safety point of view, identifying erroneous cockpit instruments for correction will re-establish the pilot's ability to determine engine condition correctly. The use of the test set is fully justified by its capability to verify cockpit instruments, which ensures that the pilot has valid engine operating conditions displayed.

Flight safety becomes the prime consideration for an engine failure when operating at low flight altitude. Periodic use of REDD in any aviation unit will improve the basis for on-condition maintenance decisions that lead to more reliable engines. Fewer problems will have to be troubleshot by removal and replacement of possibly good parts. Fewer good parts will be condemned for the wrong reason. Early identification of hidden problems will minimize secondary damage. Field repairs can be accurately validated.

These capabilities combine to provide more reliable engines that produce an improved Operational Readiness (OR) rate without the cost of repairing what is not broken.

10-1 Recommendations

The H337PA-603 test set should be fielded and used following initial engine installation, on a regular interval, during pre-phase engine runs, when a power check is failed, and for installed evaluation prior to engine removal. The REDD concept has been proven to significantly improve knowledge of an engine's performance potential and to identify abnormalities in engine modules through the use of diagnostics. The output of the data analysis program provides a level of confidence in the performance potential of an installed engine not previously possible. It gives the user a way, under almost any conditions, to verify that he has a good engine.

Maintenance manuals must direct use of the JETCAL2000® Analyzer. Successful employment of the JETCAL2000® Analyzer hinges on the maintenance manuals directing use of the equipment and maintenance personnel using REDD information in their maintenance decisions. In the case of a good engine verified by REDD, the decision is easy–fly it. But, when REDD identifies an unhealthy engine, the user may like to have expert's insight to feel comfortable about his proposed repair activities. Test data is recorded in a format that can be quickly transferred by modem or as an email attachment to any location, effectively bringing the expert to the user, anywhere, anytime. The database of both uninstalled test cell data and equivalent installed performance data has great management value. Test cell operators can compare their test results with installed test results and identify to other technicians things that may shorten on-wing time.

Implementing Stage II of this COSSI program offers the potential Navy and Marine users payback in less than two years and a combined reduction in H-46 and H-53 propulsion O&S

costs of more than 60 MILLION dollars over 10 years. The potential savings provides a compelling rational in terms of operational readiness, return on investment, and flight safety. In particular, the current impact of flying de-rated engines, for example, under-trimmed at the fuel control, by five and a half turns emphasizes the need for this maintenance analysis capability to address on-wing marginal engine problems and short on-wing times. The Navy and Marines should move to Stage II as soon as possible.

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APPENDIX B –COST ALLOCATION DETAILS H-53E and H-53J

JETCAL2000®Portable Engine Analyzer Test Set, H337PA-603

Operational Test And Evaluation (OT&E)

Life Cycle Cost Savings Study

H-53E and J Aircraft

January 28, 2003

H53 AIRCRAFT BASE LINE POWER PLANT COST ALLOCATION 1/28/03 15:44

POWER PLANT COSTS FROM VAMOSC DATA BASE, FY 01, 2 - DIGIT WUC REPORT

WUC		"I" LEVEL	"O" LEVEL	DEPOT	CONSUMABLE	
	CH53					
23	POWERPLANT	1197090	114525	1660175	485474	
29	PP INSTALLATION	3740400	1750680	3702988	2654633	
	MH53					
23	POWERPLANT	27504	855036	497574	75782	
29	PP INSTALLATION	360207	1777275	1853378	832237	
	TOTAL T64	$5,325,201	$4,497,516	$7,714,115	$4,048,126	$21,584,958

TOTAL YEARLY ENGINE COSTS = $21,585 DOLLARS X 1000
LESS FUEL AND TRANSPORTATION

COST ID		BASELINE	% ALLOC	
				PERCENTAGES BASED ON ESTIMATES
B.1.2	UNIT MAINTENANCE	$1,943	9.00%	FROM DEPOT VS. "I" LEVEL REPAIRS.
		$0		DEPOT REPAIRS CONSTITUTE 33%
B2.2	U-CONSUMABLE	$1,727	8.00%	WHILE "I" LEVEL CONSTITUTES 67%
		$0		
B.2.3	UNIT USE D REPAIR	$3,238	15.00%	
		$0		
B.3.1	IM ENGINE REWORK	$7,555	35.00%	
		$0		
B.3.2	IM CONSUMABLES	$2,806	13.00%	
		$0		
B.4.1	DEPOT ENG WORK	$4,317	20.00%	
		$0		
		$21,585	100%	

B.6.3	CALIBRATION	0	$1,000 PER YEAR PER TEST SET
B.6.8	ENG TRANSPORT D	480	

$8,000 PER ENGINE ROUND TRIP TO DEPOT X 60 ENGINES PER YEAR

JETCAL 2000® SAVINGS BREAKDOWN H53 AIRCRAFT - VALUES IN $1,000 1/28/03 15:33

++

TOTAL YEARLY SAVINGS ONE TEST UNIT = $765 PERCENT OF SAVINGS USED 40.00%

++

					TEST SETS FIELDED		COST WITH TEST SETS		
COST ID	BASELINE	% ALLOC	1 UNIT	REDUCED SAVINGS	6	11	YEAR 03	YEAR 04	YEAR 05
B.2.1	$1,943	9.00%	$69	$28	$165	$303	$1,915	$1,777	$1,640
	$0		$0	$0	$0	$0	$0	$0	$0
B2.2	$1,727	8.00%	$61	$24	$147	$269	$1,702	$1,580	$1,458
	$0		$0	$0	$0	$0	$0	$0	$0
B.2.3	$3,238	15.00%	$115	$46	$275	$505	$3,192	$2,962	$2,733
	$0		$0	$0	$0	$0	$0	$0	$0
B.3.1	$7,555	35.00%	$268	$107	$643	$1,178	$7,448	$6,912	$6,377
	$0		$0	$0	$0	$0	$0	$0	$0
B.3.2	$2,806	13.00%	$99	$40	$239	$438	$2,766	$2,567	$2,368
	$0		$0	$0	$0	$0	$0	$0	$0
B.4.1	$4,317	20.00%	$153	$61	$367	$673	$4,256	$3,950	$3,644
	TOTALS	100.00%	$765	$306					
B.6.3	0		$0	$0	$0	$0	$1	$6	$10
			$0	$0	$0	$0	$0	$0	$0
B.6.8	480		$0	$0	$0	$0	$472	$432	$396
			$0	$0	$0	$0	$0	$0	$0
SAVINGS/COSTS YEARLY TOTAL			$765	$306	$1,836	$3,366	$21,752	$20,187	$18,625
PERCENT OF SAVINGS USED				40.00%					

++

Proposal Title PORTABLE TEST CELL - JETCAL 2000(R)
Lead Proposer HOWELL INSTRUMENTS
Military Customer NAVY/MARINE H53 AIRCRAFT

-

DoD Costs when COSSI Project is Implemented

Cost data for each government fiscal year should be entered in blue cells in constant FY2002 ($K)

Stage I -- All Costs to the DoD of implementing Stage I

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Howell Inst.	Data Acquisition Unit	A.1.1.1	80									
Howell Inst.	Installation Kit	A.1.1.1	100									
	Total		180	-	-	-	-	-	-	-	-	-
	Present Value (Discounted) Total		175	-	-	-	-	-	-	-	-	-
	@ Discount Rate of	3.1%										

Stage II -- Costs to the government of purchasing and installing kits during Stage II

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Howell Inst.	Data Acquisition Unit	A.2.1	385	385							-	-
Howell Inst.	Installation Kit	A.2.1	786	786								
Howell Inst.	Maintenance Contract	A.2.2		160	320	320	320					
Howell Inst.	Technical Support	A.2.3		75	75	75						
	Total		1,171	1,406	395	395	320	-	-	-	-	-
	Present Value (Discounted) Total		1,136	1,323	360	350	275	-	-	-	-	-
	@ Discount Rate of	3.1%										

O&S Costs When COSSI Project is Implemented

Do not duplicate any costs already covered in the Stage I and Stage II tables just above

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
VAMOSC	UNIT MAINTENANCE	B.1.2	$1,915	$1,777	$1,640	$1,640	$1,640	$1,640	$1,640	$1,640	$1,640	$1,640
	-	-	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
VAMOSC	U CONSUMABLE	B.2.2	$1,702	$1,580	$1,458	$1,458	$1,458	$1,458	$1,458	$1,458	$1,458	$1,458
	-	-	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
VAMOSC	UNIT USE DEPOT REPAIRABLES	B.2.3	$3,192	$2,962	$2,733	$2,733	$2,733	$2,733	$2,733	$2,733	$2,733	$2,733
	-	-	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
VAMOSC	IM ENGINE REWORK	B.3.1	$7,448	$6,912	$6,377	$6,377	$6,377	$6,377	$6,377	$6,377	$6,377	$6,377
	-	-	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
VAMOSC	IM CONSUMABLES	B.3.2	$2,766	$2,567	$2,368	$2,368	$2,368	$2,368	$2,368	$2,368	$2,368	$2,368
	-	-	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
VAMOSC	DEPOT ENGINE REWORK	B.4.1	$4,256	$3,950	$3,644	$3,644	$3,644	$3,644	$3,644	$3,644	$3,644	$3,644
	-	-										
Howell Inst.	PERIODIC CALIBRATION	B.6.3	1	6	10	10	10	10	10	10	10	10
	-	-										
VAMOSC	DEPOT ENGINE TRANSPORT	B.6.8	480	452	423	404	404	404	404	404	404	404
	Total		21,760	20,207	18,652	18,633	18,633	18,633	18,633	18,633	18,633	18,633
	Present Value (Discounted) Total		21,106	19,010	17,020	16,491	15,995	15,514	15,048	14,595	14,156	13,731

Proposal Title	PORTABLE TEST CELL - JETCAL 2000(R)
Lead Proposer	HOWELL INSTRUMENTS
Military Customer	NAVY/MARINE H53 AIRCRAFT

Baseline Costs -- DoD's Costs When COSSI is NOT Implemented

Cost data for each government fiscal year should be entered in blue cells in constant FY2002 ($K)

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
VAMOSC	UNIT MAINTENANCE	B.1.2		1,943	1,943	1,943	1,943	1,943	1,943	1,943	1,943	1,943	1,943
				-	-	-	-	-	-	-	-	-	-
VAMOSC	U CONSUMABLE	B.2.2		1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727
				-	-	-	-	-	-	-	-	-	-
VAMOSC	UNIT USE DEPOT REPAIRABLES	B.2.3		3,238	3,238	3,238	3,238	3,238	3,238	3,238	3,238	3,238	3,238
				-	-	-	-	-	-	-	-	-	-
VAMOSC	IM ENGINE REWORK	B.3.1		7,555	7,555	7,555	7,555	7,555	7,555	7,555	7,555	7,555	7,555
				-	-	-	-	-	-	-	-	-	-
VAMOSC	IM CONSUMABLES	B.3.2		2,806	2,806	2,806	2,806	2,806	2,806	2,806	2,806	2,806	2,806
				-	-	-	-	-	-	-	-	-	-
VAMOSC	DEPOT ENGINE REWORK	B.4.1		4,317	4,317	4,317	4,317	4,317	4,317	4,317	4,317	4,317	4,317
Howell Inst.	PERIODIC CALIBRATION	B.6.3		-	-	-	-	-	-	-	-	-	-
VAMOSC	DEPOT ENGINE TRANSPORT	B.6.8		480	480	480	480	480	480	480	480	480	480
	Total			22,065	22,065	22,065	22,065	22,065	22,065	22,065	22,065	22,065	22,065
	Present Value (Discounted) Total			21,402	20,758	20,134	19,529	18,941	18,372	17,819	17,284	16,764	16,260
	@ Discount Rate of		3.1%										

Labor Manyears Associated With Above Costs

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
MILPERS Manyears		430	430	430	430	430	430	430	430	430	430
Labor Rate/Hr.											
CIVPERS Manyears											
Labor Rate/Hr.											

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APPENDIX C –COST ALLOCATION DETAILS H-46D and H-46E

JETCAL2000®Portable Engine Analyzer Test Set, H337PA-603
Operational Test And Evaluation (OT&E)
Life Cycle Cost Savings Study
H-46D and E Aircraft

January 28, 2003

H-46/T58 BASE LINE POWER PLANT YEARLY COST 1/28/03 16:20

		"I" LEVEL	DEPOT	CONSUMABLE	"O" level	
	H-46D					
VAMOC TMS QUERY		137855	679354	399705		WUC NOT AVAIL.
WUC	H-46E					
23	POWERPLANT	132570	497574	1068507	1227195	
29	PP INSTALLATION	1471815	1853378	4222749	2330505	
	TOTAL T58	$1,742,240	$3,030,306	$5,690,961	9246593	$19,710,100
			LESS FUEL COST =			-$1,217,000
	TOTAL YEARLY POWER PLANT COST FOR ALLOCATION=					$18,493,100

****

H-46/T58 AIRCRAFT BASE LINE ALLOCATION VALUES IN $1,000

TOTAL YEARLY POWER PLANT COST = $18,493 LESS FUEL COST AND TRANSPORTATION

COST ID	BASELINE		% ALLOC	
B.1.2	UNIT MAINTENANCE	$1,664	9%	ALLOCATION PERCENTAGES BASED ON ESTIMATES FROM DEPOT VERSUS "I" LEVEL REPAIRS. DEPOT DID 79 OR 33%, "I" LEVEL DID 158 OR 67%
B.2.2	U-CONSUMABLES	$1,479	8%	
B.2.5	UNIT USE D REPAIR	$2,774	15%	
B.3.1	IM ENGINE REWORK	$6,473	35%	
B.3.2	IM CONSUMABLES	$2,404	13%	
B.4.1	DEPOT ENg REWORK	$3,699	20%	
	TOTAL ALLOCATION	$18,493	100%	
B.6.3	CALIBRATION	$1		$1,000 PER TEST SET PER YEAR
B.6.8	TRANSPORT	$632		

ENGINE ROUND TRIP TO DEPOT = $8,000 X ENgINES PER YEAR = 79

****

*

Proposal Title PORTABLE ENGINE TEST CELL
Lead Proposer HOWELL INSTRUMENTS
Military Customer NAVY/MARINE H46 AIRCRAFT

Baseline Costs -- DoD's Costs When COSSI is NOT Implemented

Cost data for each government fiscal year should be entered in blue cells in constant FY2002 ($K)

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
VAMOSC	UNIT MAINTENANCE	B.1.2	1,664	1,664	1,664	1,664	1,664	1,664	1,664	1,664	1,664	1,664
VAMOSC	UNIT CONSUMABLES	B.2.2	1,479	1,479	1,479	1,479	1,479	1,479	1,479	1,479	1,479	1,479
VAMOSC	UNIT USED D.R.	B.2.3	2,774	2,774	2,774	2,774	2,774	2,774	2,774	2,774	2,774	2,774
VAMOSC	IM ENGINE REWORK	B.3.1	6,473	6,473	6,473	6,473	6,473	6,473	6,473	6,473	6,473	6,473
VAMOSC	IM CONSUMABLES	B.3.2	2,404	2,404	2,404	2,404	2,404	2,404	2,404	2,404	2,404	2,404
VAMOSC	DEPOT ENGINE REWORK	B.4.1	3,699	3,699	3,699	3,699	3,699	3,699	3,699	3,699	3,699	3,699
Howell Inst.	PERODIC CAL	B.6.3	1	6	11	11	11	11	11	11	11	11
VAMOSC	ENGINE TRANSPORT	B.6.8	640	640	640	640	640	640	640	640	640	640
	Total		19,134	19,139	19,144	19,144	19,144	19,144	19,144	19,144	19,144	19,144
	Present Value (Discounted) Total		18,559	18,005	17,469	16,943	16,434	15,940	15,460	14,996	14,545	14,107
	@ Discount Rate of	3.1%										

Labor Manyears Associated With Above Costs

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
MILPERS Manyears		1,640	1,640	1,640	1,640	1,640	1,640	1,640	1,640	1,640	1,640
Labor Rate/Hr.											
CIVPERS Manyears											
Labor Rate/Hr.											

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JETCAL 2000® SAVINGS BREAKDOWN - H46 AIRCRAFT 1/28/03 16:22

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TOTAL YEARLY SAVINGS 1 TEST UNIT = $765 % of Savings used = 33%

COST ID	BASELINE	% ALLOC 100%	1 UNIT Savings	Savings Used	Units used 6	Units used 10	YEAR 03	YEAR 05	YEAR 06
B.2.1	$1,664	9%	$69	$23	$136	$227	$1,642	$1,528	$1,437
B2.2	$1,479	8%	$61	$20	$121	$202	$1,459	$1,358	$1,277
B.2.3	$2,774	15%	$115	$38	$227	$379	$2,736	$2,547	$2,395
B.3.1	$6,473	35%	$268	$88	$530	$884	$6,384	$5,942	$5,589
B.3.2	$2,404	13%	$99	$33	$197	$328	$2,371	$2,207	$2,076
B.4.1	$3,699	20%	$153	$50	$303	$505	$3,648	$3,396	$3,194
A-TOTAL	$18,493	100%	$765	$252	$1,515	$2,525	$18,241	$16,978	$15,969
B.6.3	0						$1	$6	$11
B.6.8	624			$8	$48	$88	$616	$576	$536
SAVINGS YEARLY/ TOTAL			$1,530	$513 34%	$3,077	$5,137	$37,098	$34,539	$32,484

Proposal Title PORTABLE ENGINE TEST CELL
Lead Proposer HOWELL INSTRUMENTS
Military Customer NAVY/MARINE H46 AIRCRAFT

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DoD Costs when COSSI Project is Implemented

Cost data for each government fiscal year should be entered in blue cells in constant FY2002 ($K)

Stage I -- All Costs to the DoD of implementing Stage I

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Howell Inst.	Data Acqusition Unit	A.1.1.1	80									
Howell Inst.	Installation Kit	A.1.1.1	100									
	Total		180	-	-	-	-	-	-	-	-	-
	Present Value (Discounted) Total		175	-	-	-	-	-	-	-	-	-
	@ Discount Rate of	3.1%										

Stage II -- Costs to the government of purchasing and installing kits during Stage II

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Howell Inst.	Data Acqusition Unit	A.2.1	385	308								
Howell Inst.	Installation Kit	A.2.1	620	496								
Howell Inst.	Maintenance Contract	A.2.2		210	210	210						
Howell Inst.	Technical Support	A.2.3	75	75	75							
	Total		1,080	1,089	285	210	-	-	-	-	-	-
	Present Value (Discounted) Total		1,048	1,024	260	186	-	-	-	-	-	-
	@ Discount Rate of	3.1%										

O&S Costs When COSSI Project is Implemented

Do not duplicate any costs already covered in the Stage I and Stage II tables just above

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
VAMOSC	UNIT MAINTENANCE	B.1.2	$1,642	$1,528	$1,414	$1,414	$1,414	$1,414	$1,414	$1,414	$1,414	$1,414
	-	-										
VAMOSC	UNIT CONSUMABLES	B.2.2	$1,459	$1,358	$1,257	$1,257	$1,257	$1,257	$1,257	$1,257	$1,257	$1,257
	-	-										
VAMOSC	UNIT USED D.R.	B.2.3	$2,736	$2,547	$2,357	$2,357	$2,357	$2,357	$2,357	$2,357	$2,357	$2,357
	-	-										
VAMOSC	IM ENGINE REWORK	B.3.1	$6,384	$5,942	$5,501	$5,501	$5,501	$5,501	$5,501	$5,501	$5,501	$5,501
	-	-										
VAMOSC	IM CONSUMABLES	B.3.2	$2,371	$2,207	$2,043	$2,043	$2,043	$2,043	$2,043	$2,043	$2,043	$2,043
	-	-										
VAMOSC	DEPOT ENGINE REWORK	B.4.1	$3,648	$3,396	$3,143	$3,143	$3,143	$3,143	$3,143	$3,143	$3,143	$3,143
	-	-										
Howell Inst.	PERODIC CAL	B.6.3	1	6	10	10	10	10	10	10	10	10
	-	-										
VAMOSC	ENGINE TRANSPORT	B.6.8	620	614	604	604	604	604	604	604	604	604
	Total		18,862	17,598	16,330	16,330	16,330	16,330	16,330	16,330	16,330	16,330
	Present Value (Discounted) Total		18,294	16,556	14,901	14,453	14,018	13,597	13,188	12,791	12,407	12,034
	@ Discount Rate of	3.1%										

Proposal Title	PORTABLE TEST CELL - JETCAL 2000(R)
Lead Proposer	HOWELL INSTRUMENTS
Military Customer	NAVY/MARINE H53 AIRCRAFT

Baseline Costs -- DoD's Costs When COSSI is NOT Implemented

Cost data for each government fiscal year should be entered in blue cells in constant FY2002 ($K)

Data Source	Cost Element	Generic DoD Cost Element Cross Ref.	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
VAMOSC	UNIT MAINTENANCE	B.1.2	1,943	1,943	1,943	1,943	1,943	1,943	1,943	1,943	1,943	1,943
			-	-	-	-	-	-	-	-	-	-
VAMOSC	U CONSUMABLE	B.2.2	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727	1,727
			-	-	-	-	-	-	-	-	-	-
VAMOSC	UNIT USE DEPOT REPAIRABLES	B.2.3	3,238	3,238	3,238	3,238	3,238	3,238	3,238	3,238	3,238	3,238
			-	-	-	-	-	-	-	-	-	-
VAMOSC	IM ENGINE REWORK	B.3.1	7,555	7,555	7,555	7,555	7,555	7,555	7,555	7,555	7,555	7,555
			-	-	-	-	-	-	-	-	-	-
VAMOSC	IM CONSUMABLES	B.3.2	2,806	2,806	2,806	2,806	2,806	2,806	2,806	2,806	2,806	2,806
			-	-	-	-	-	-	-	-	-	-
VAMOSC	DEPOT ENGINE REWORK	B.4.1	4,317	4,317	4,317	4,317	4,317	4,317	4,317	4,317	4,317	4,317
Howell Inst.	PERIODIC CALIBRATION	B.6.3	-	-	-	-	-	-	-	-	-	-
VAMOSC	DEPOT ENGINE TRANSPORT	B.6.8	480	480	480	480	480	480	480	480	480	480
	Total		22,065	22,065	22,065	22,065	22,065	22,065	22,065	22,065	22,065	22,065
	Present Value (Discounted) Total		21,402	20,758	20,134	19,529	18,941	18,372	17,819	17,284	16,764	16,260
	@ Discount Rate of	3.1%										

Labor Manyears Associated With Above Costs

MILPERS Manyears		430	430	430	430	430	430	430	430	430	430
Labor Rate/Hr.											
CIVPERS Manyears											
Labor Rate/Hr.											

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